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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
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INFORMATION CIRCULAR

# AERIAL TRAMWAYS IN THE METAL-MINING INDUSTRY

## PART 2. CONSTRUCTION AND OPERATING COSTS

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BY

O. H. METZGER

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## UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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# AERIAL TRAMWAYS IN THE METAL MINING INDUSTRY[1]

## Part 2. Construction and Operating Costs

By O. H. Metzger[2]

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7095."

[2] Associate mining engineer, Mining Division, Bureau of Mines, U. S. Dept. of the Interior.

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## INTRODUCTION

This is the second of two papers dealing with the construction and use of aerial tramways in the metal-mining industry. The first paper[3] described aerial tramways in a general way and discussed the engineering principles used in tramway design. The purpose of this paper is to give a more detailed description of equipment and material and to discuss construction and operating costs.

## ACKNOWLEDGMENTS

The paper is based largely on data from actual operations. Metal-mine operators from many parts of the United States, Canada, Alaska, and Mexico contributed liberally.

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[3] Metzger, O. H., Aerial Tramways in the Metal-Mining Industry. Part 1: Bureau of Mines Inf. Circ. 6948, 1937, 32 pp.

# CONSTRUCTION COSTS

## General Considerations

Costs of tramway construction probably are more difficult to estimate ian those of most other types. Design is influenced largely by topography id climatic conditions. General conditions affecting costs vary so greatly iat every individual line, and in some instances, every individual structure, s a problem in itself. Cost of materials and equipment for a given design an be estimated easily and accurately. Erection costs, however, are more ifficult to forecast. The cost of delivering the material and erecting a tructure at one part of a line may be twice or even three times as great as or a structure of identical size and design at another part of the same line. uch extreme range in labor costs for jobs that appear identical may be the ule rather than the exception in situations of rough topography where aerial ramways find their greatest field of usefulness in the metal-mining industry.

## Preliminary Costs

Preliminary costs might be considered to include all costs that accrue efore actual construction begins. These expenses may be negligible or may mount to 15 percent or more of the total cost of the tramway. Generally, owever, they are much less than 15 percent.

## Surveying

A tramway survey comprises running a center line and determining horizontal nd vertical distances to the nearest one-hundredth of a foot, and making an ccurate topographic survey of each structure location. The cost of this survey covers field and office work and incidental items. Short trams in countries ith plane topography may be built after an inexpensive survey. In countries f rough topography, however, surveying costs may be considerable. Months of reliminary surveying are sometimes necessary to find the most favorable route. his is often so where angle stations are required. An example of this is the ramway of the Silbak Premier Mines, Ltd., at Premier, British Columbia.[4] reliminary surveys for this tramway were initiated the season before construcion began and the surveying cost was approximately $550 a mile.

## Right-of-Way

Right-of-way costs include any legal or other expenditures required to et permission to build a tramway on private or public property. It may be ifficult and costly to procure a right-of-way in certain thickly populated reas. In most metal-mining districts in the western United States, however, ight-of-way costs are negligible. Aerial tramways are less damaging to roperty than any other means of surface transportation. Even when they ross cultivated fields, the damage is comparatively slight and in many

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/ Pitt, Dale L., Aerial Tramway Construction and Operation: Trans. Canadian Inst. Min. and Met., 1930.

instances negligible. Only from 100 to 200 or 300 square feet of ground is required for each tower or support. If the topography permits long spacing of supports, the property damage is no greater than that of a power transmission line.

The cost of clearing right-of-way is high in heavily timbered countries. In certain parts of the western United States, Canada, and Alaska and in many tropical regions, clearing of right-of-way may cost as much as $2,000 or more per mile. Generally, a strip 50 feet on each side of the center line, or a total of 100 feet, is cleared. If the timber is tall it may be necessary to clear a wider strip so that the tallest tree at the edge of the clearing would not damage the tramway in falling. Clearing costs for the Premier tramway and the Porter-Idaho tramway,[5] both of the Silbak Premier Mines, Ltd., of Premier, British Columbia, were approximately $2,000 and $1,800 per mile, respectively.

## Engineering Design

Nearly all aerial tramways are designed by private consulting tramway engineers or by the engineering staffs of tramway manufacturers. Exceptions are tramways built from old or used equipment. A number of successful lines of this latter kind have been built at small to medium-size metal mines in the western United States by mining engineers who did not profess any special knowledge of tramway engineering. Some manufacturers will supply material according to the specifications of private consultants; others, however, frown upon the practice. Regardless of what the arrangement may be between customer and vendor, engineering costs are paid by the customer in the end, either directly or indirectly. Some companies make a direct charge for their engineering services, whereas others pass the cost on to the customer in other ways. The first of these is the more businesslike and probably is more satisfactory in the end.

Consulting tramway engineers often will contract to design a tramway, bargain for material and equipment in the most favorable markets, and supervise construction. By such an arrangement, engineering and supervision costs sometimes can be cut to a minimum. It is not suggested, however, that this is always the best arrangement. The question as to whether a private consultant should be employed in this capacity or in an advisory capacity only depends on many things, but perhaps more on the personalities involved than on any other factor.

There are relatively few experienced consulting tramway engineers; they are located in such widely separated places as New York, N. Y.; Chicago, Ill.; Dallas, Tex.; Denver, Colo.; and San Francisco, Calif.

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[5] Pitt, Dale L., Work cited in footnote 4.

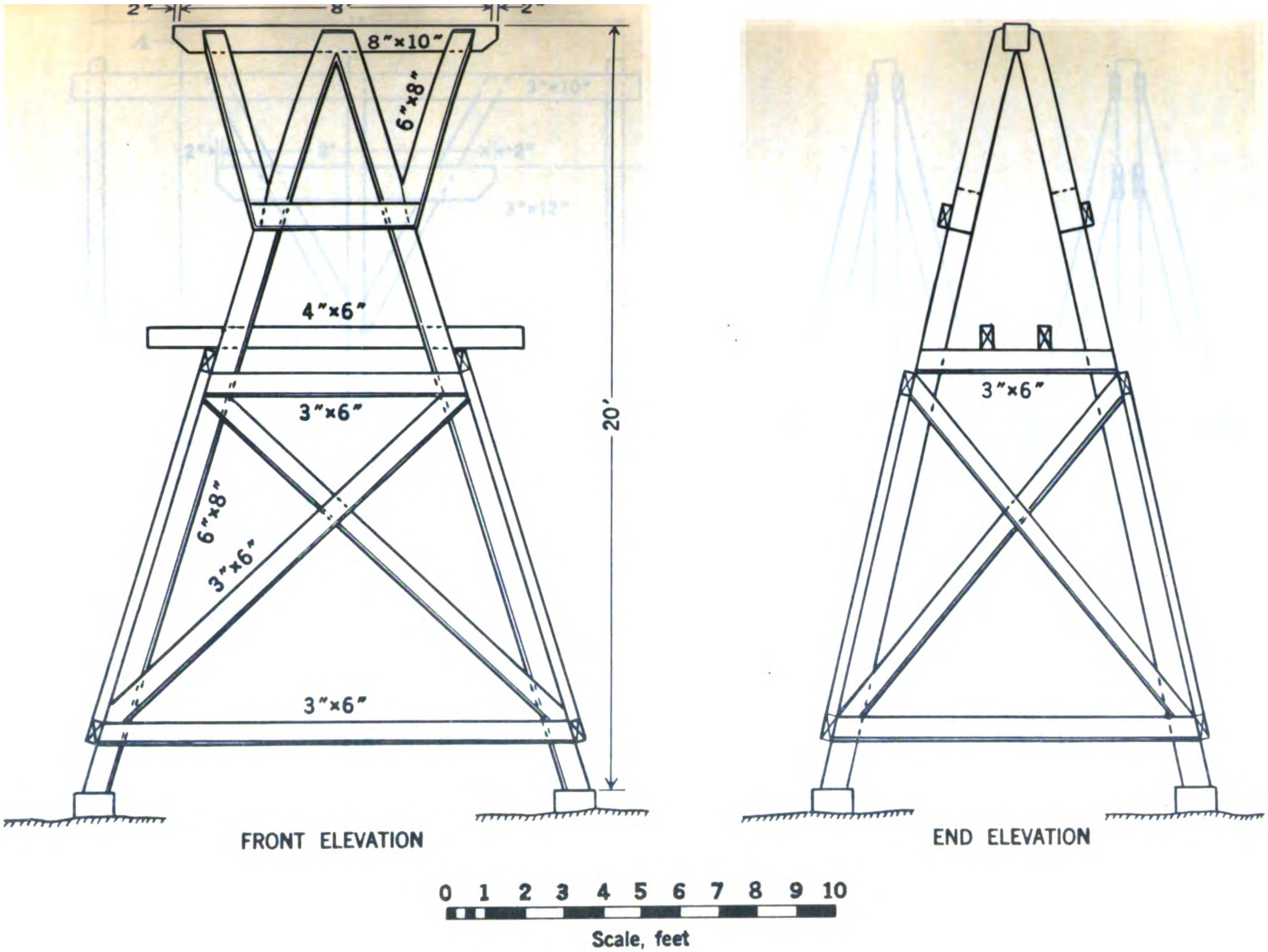

Figure 1.—Pyramid tower, timber construction.

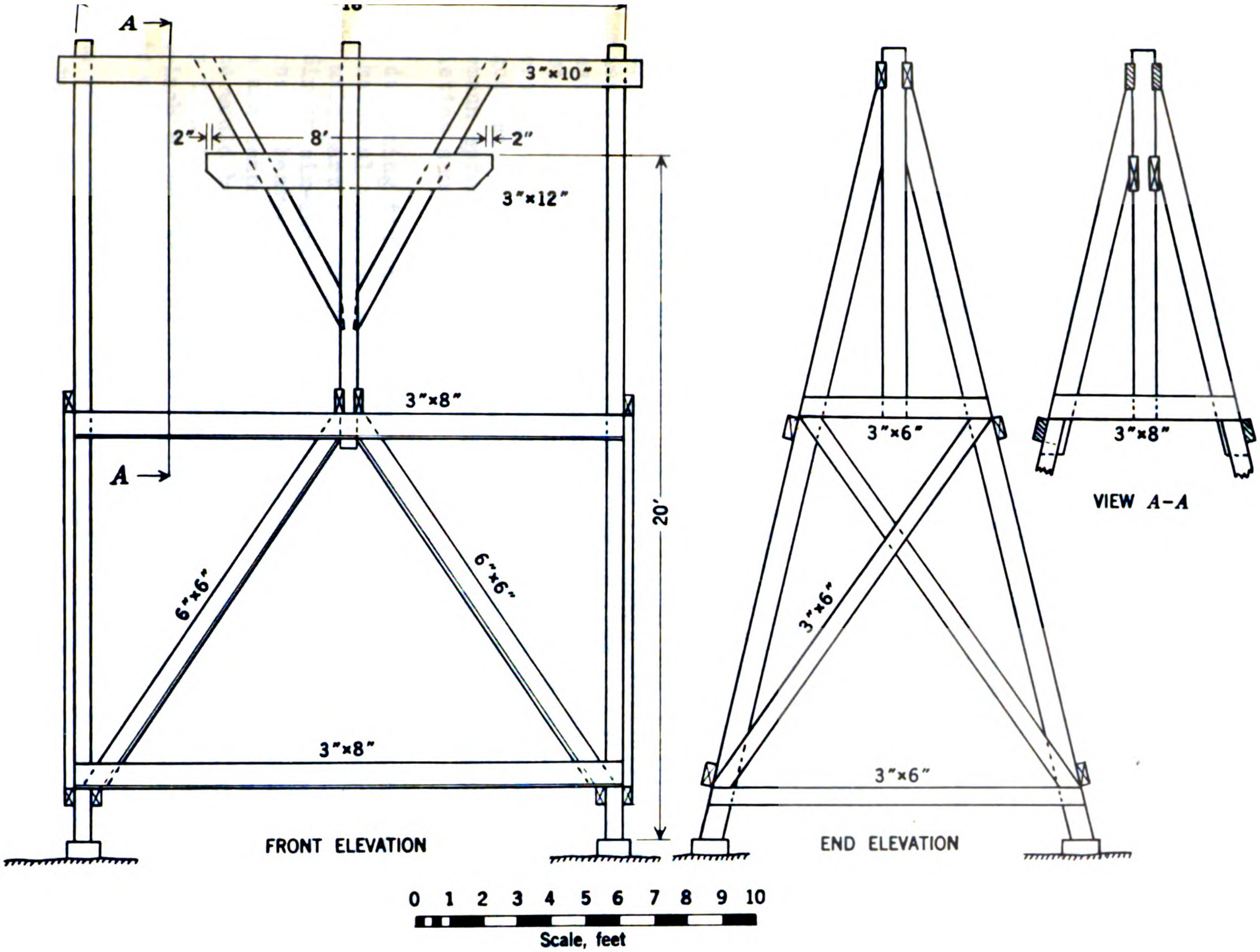

Figure 2.–Through tower, timber construction.

## Transportation

The costs of transporting construction materials require but little discussion. In this paper, they will be considered to include the costs of transporting material and equipment from the source of supply to the general site of the tramway, but not the cost of distributing them to the various places where they are to be used ultimately. It is thought to be more logical to include the latter in erection or installation costs. In general, transportation costs would include freight charges by rail or water, or both, from the source of supply to the nearest unloading station, and a trucking or draying charge from the unloading station to the general site of the tramway.

Certain materials for construction purposes generally can be purchased locally, whereas others must be obtained at the source of supply and sometimes shipped thousands of miles to where they are to be used. This may sometimes determine the type of construction to employ.

## Material

### Timber

Timber is generally the handiest and most easily obtainable material for structural purposes. The coast variety of Douglas fir is the most satisfactory timber for any kind of construction work in the Western United States. Other kinds that are satisfactory are the Rocky Mountain variety of Douglas fir, sometimes called red spruce, and Ponderosa or Western yellow pine. A good grade of timber of one or more of these varieties is always available in almost any part of the western United States at prices ranging from $30 to $50 per thousand board feet. Any good grade of structural timber that has been properly seasoned will last the life of the tramway in most western climates. Tramway towers built more than 40 years ago in southwestern Colorado are still standing in a fairly good state of preservation. Many of these were built from a medium grade of Englemann spruce, which is inferior in its weather-resisting qualities to the varieties named above.

In designing timber tramway structures the tendency is to use much heavier material than is necessary; 8- by 8-inch timbers very often are used for the main part of structures for which 6- by 8-inch would serve just as well. Six by six-inch timbers sometimes are used for building all line structures of heavy-duty systems used in the construction industry. Inasmuch as these are temporary lines, it is possible to use lighter construction than otherwise would be advisable. The fact, however, that some are of larger capacity than the average heavy-duty mine tramway leads to the belief that 6- by 6-inch select timbers might be suitable even for permanent lines of small to moderate capacity.

The amount of timber required to build a tower of a certain height depends on the type of tower as well as the size of timbers. Figures 1 and 2 are designs of two towers, one of the pyramid type and the other the through type. Table 1 shows the cost and weight per linear foot and the compressive strength of various sizes of timber suitable for building such structures. For comparison, the same data are shown for a number of steel sections. Table 2 gives the amount, cost, and weight of timber or steel required to build the structures shown in figures 1, 2, 3, 4, and 5. The structures shown in figures 3 and 5 are of steel construction; all of the rest are of timber construction.

Tension stations, anchor stations, and rail sections generally are built from the same kind and size of material as the supporting towers. Heavier timbers sometimes are used for the center posts than for the outside posts of tension and anchor stations. Figures 4 and 5 show the designs of typical double-tension stations in timber and steel, and table 2 shows the amount, cost, and weight of material required; about 20 percent less material is required for a double anchor station. Rail sections vary so greatly in length, height, and design that no attempt is made here to show the amount or cost of material required to build them.

Size and plan of loading and discharge terminals depend to a great extent on topography and bin capacity required. If the tram is to be used for transporting timbers and supplies from discharge terminal to loading terminal, extra floor space must be provided for storage and handling; track for mine cars and extra switch rails must also be considered. At many metal mining plants the loading terminal may be part of a crushing plant and the discharge terminal a part of a mill. At such plants, terminal costs may be reduced greatly.

## Steel

Steel is preferred to timber for structural purposes by many tramway engineers. For the same strength it is lighter than timber and consequently the erecting costs are less. Total over all costs, however, are considerably higher. It is seldom possible to purchase structural steel locally. Most rolling mills and fabricating plants are in the East and Middle West, with a few scattered over the Rocky Mountain region and the Pacific coast.

It is customary when building with steel to submit drawings of each structure to a fabricating plant. The members required are cut and punched according to the drawings and shipped to the customer ready for erecting. Sometimes the steel is purchased direct from the rolling mills and fabricated at a makeshift plant on the ground where it is to be used. It is claimed tha a saving may result from this latter practice.

Angles from 3- by 3- by 3/8-inch to 4- by 4- by 1/2-inch are suitable for the main structure work on tramways with a capacity up to about 60 tons per hour. Lighter angles are used for braces and 3- by 7-inch channels for saddle beams. Prices, unit weights, and compressive and tensile strengths of various sections are shown in table 1. Figures 3 and 5 show typical designs for steel structures, and table 2 shows the cost and weight of material required to build these structures according to the designs.

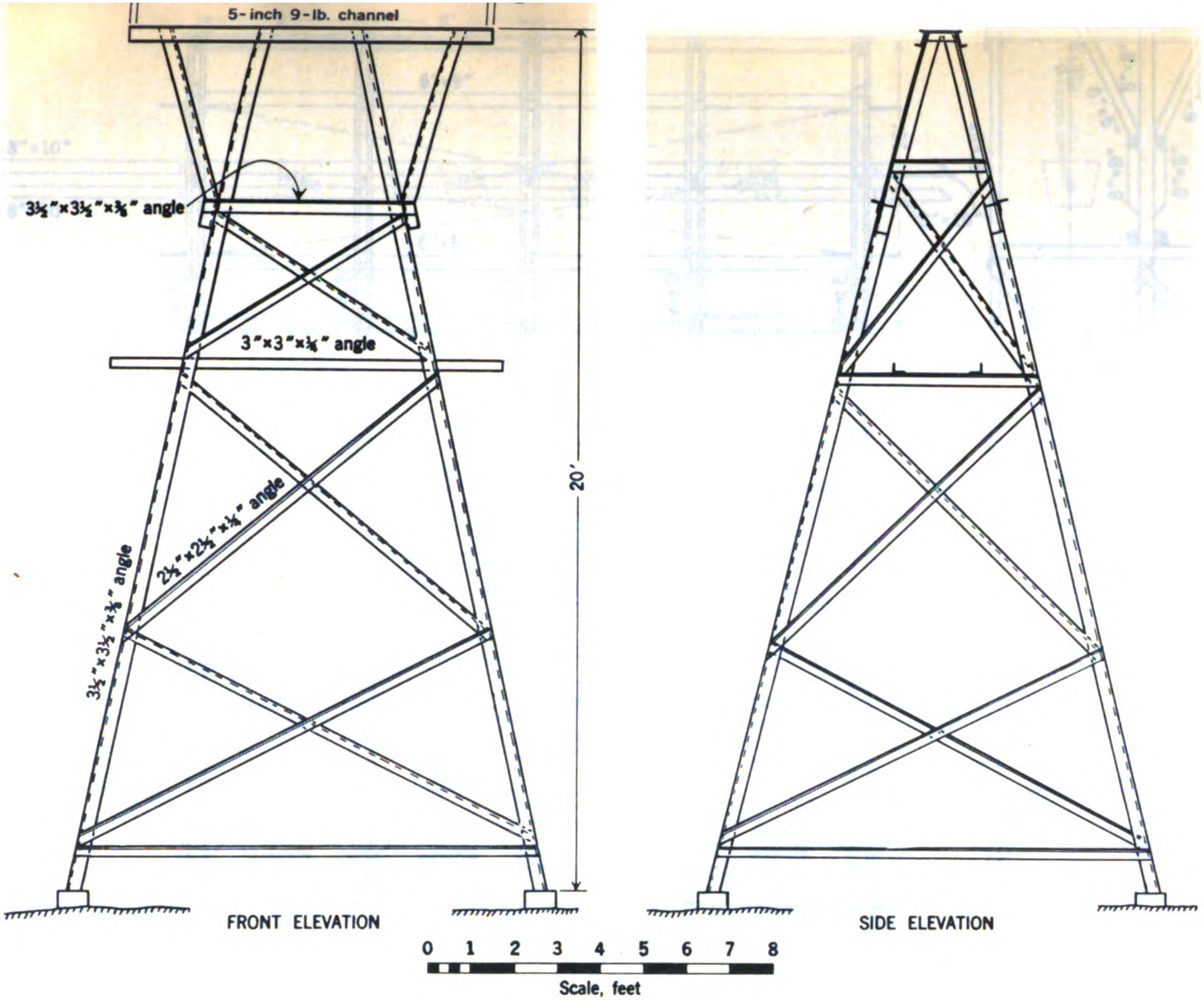

Figure 3.—Pyramid tower, steel construction.

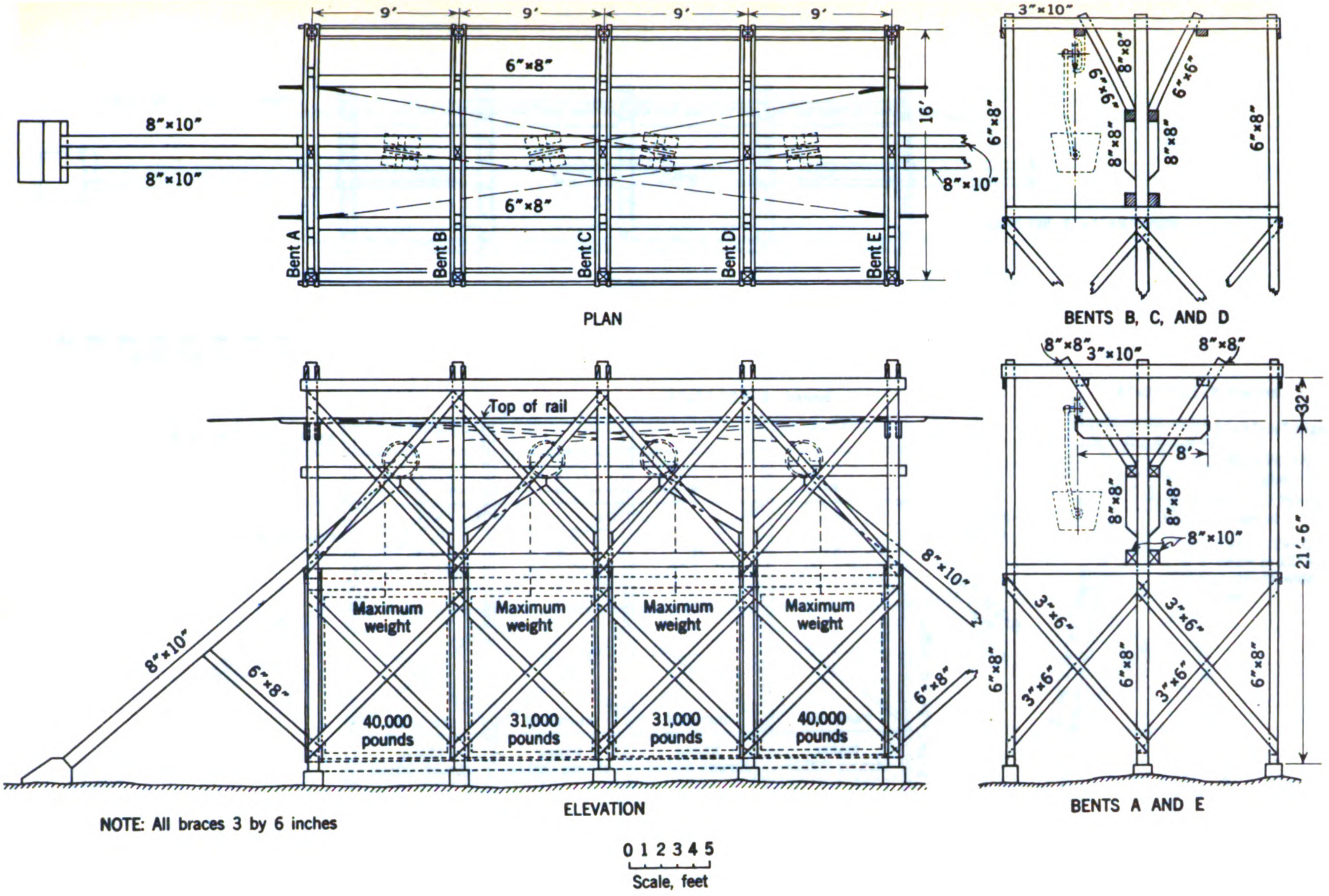

Figure 4.—Tension station, timber construction.

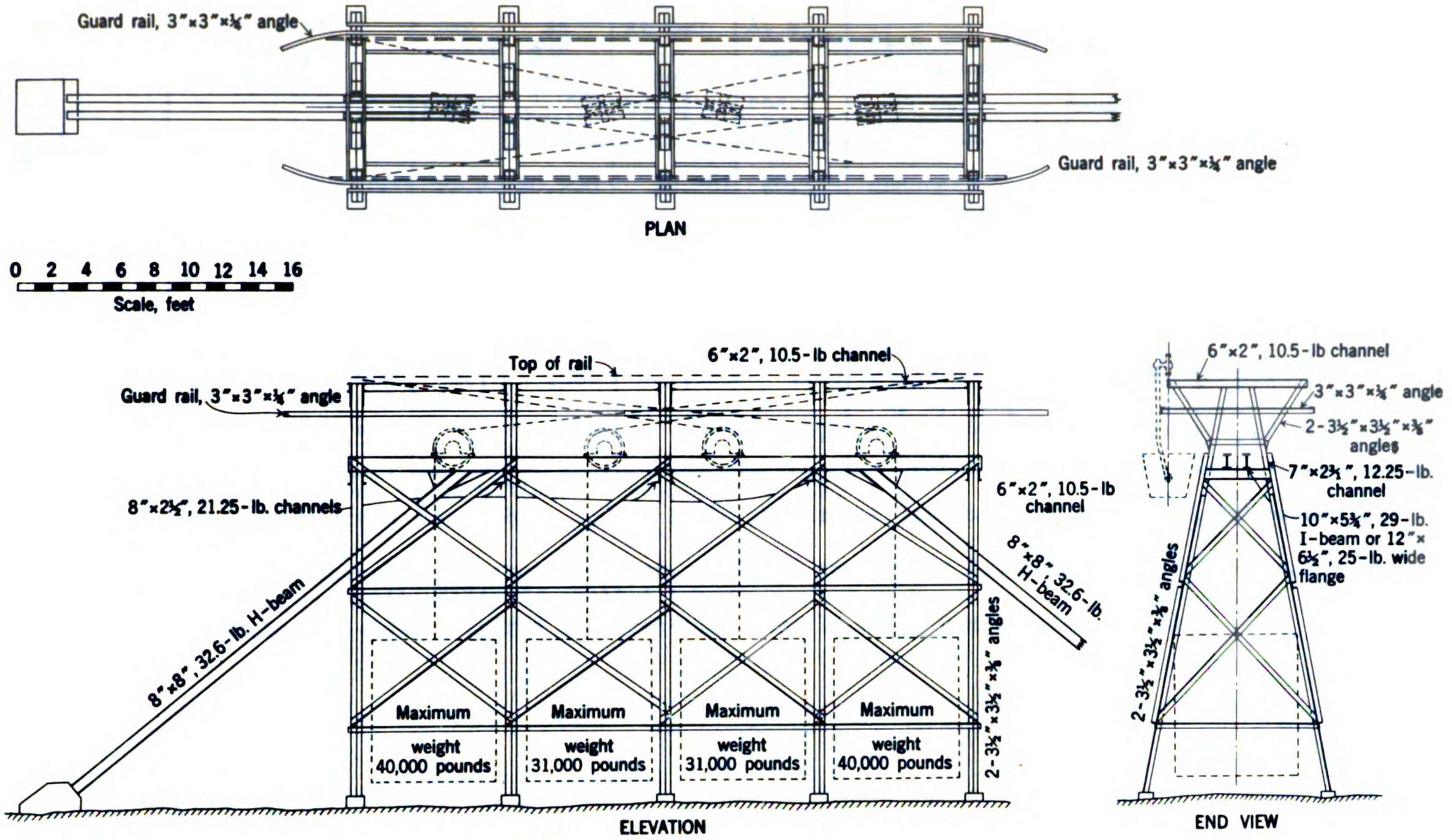
Guard rail, 3″×3″×¼″ angle
Guard rail, 3″×3″×¼″ angle
PLAN
0 2 4 6 8 10 12 14 16
Scale, feet
Top of rail
6″×2″, 10.5-lb channel
Guard rail, 3″×3″×¼″ angle
8″×2½″, 21.25-lb. channels
8″×8″, 32.6-lb. H-beam
6″×2″, 10.5-lb channel
8″×8″, 32.6-lb. H-beam
2-3½″×3½″×⅜″ angles
Maximum weight 40,000 pounds
Maximum weight 31,000 pounds
Maximum weight 31,000 pounds
Maximum weight 40,000 pounds
ELEVATION
6″×2″, 10.5-lb channel
3″×3″×¼″ angle
2-3½″×3½″×⅜″ angles
7″×2¼″, 12.25-lb. channel
10″×5¾″, 29-lb. I-beam or 12″×6½″, 25-lb. wide flange
2-3½″×3½″×⅜″ angles
END VIEW

Figure 5.—Tension station, steel construction.

**TABLE 1. – Comparative properties of timber and steel[1]**

| Member | Timber | | | | | | Steel | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Size inches | Allowable compressive strength, pounds[2] | Weight per linear foot pounds | Cost per linear foot[3] | | | Size and shape, inches | Allowable compressive strength pounds[2] | Weight per linear foot, pounds | Cost per linear foot at $120 per ton[4] |
| | | | | At $30 per 1,000 board feet | At $40 per 1,000 board feet | At $50 per 1,000 board feet | | | | |
| Saddle beams | 8 by 10 | 60,000 to 100,000 | 22.2 | $0.200 | $0.267 | $0.334 | 6 by 2 channels | 68,700 | 13.0 | $0.78 |
| Legs | 8 by 8 | 48,000 to 80,000 | 17.8 | .160 | .213 | .267 | 4 by 4 by 1/2 angles | 67,500 | 12.8 | .770 |
| Do. | 6 by 8 | 36,000 to 60,000 | 13.0 | .120 | .160 | .200 | 3-1/2 by 3-1/2 by 3/8 angle | 45,000 | 8.5 | .510 |
| Do. | 6 by 6 | 27,000 to 45,000 | 10.0 | .090 | .120 | .150 | 3 by 3 by 3/8 angle | 38,000 | 7.2 | .430 |
| Braces | 3 by 8 | 18,000 to 30,000 | 6.7 | .060 | .080 | .100 | 2-1/2 by 2-1/2 by 1/4 angle | 21,500 | 4.1 | .246 |
| Do. | 3 by 6 | 13,500 to 22,500 | 5.0 | .045 | .060 | .075 | 2 by 2 by 1/4 angle | 17,000 | 3.2 | .192 |

1/ American Institute of Steel Construction, 2d ed., January 1934.

2/ Allowable compressive stress for timber, 750 to 1,250 pounds per square inch; steel, 18,000 pounds per square inch.

3/ Costs based on rough-dimensioned unframed lumber. Add $35 to $50 per 1,000 board feet for framing and erecting, depending on availability of skilled labor.

4/ Cost based on fabricated steel prepared for erecting. Add 10 to 15 percent for erecting.

TABLE 2. - Cost of labor and material required for steel and timber tramway structures

| Structure | Fig. No. | Height feet | Structural material | Board feet | Weight, pounds | Cost of Material | | | Framing and erecting costs1/ | | Total2/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Unframed timber at $40 per 1,000 board feet | Bolts for timber structures | Fabricated steel at $120 per ton | Timber $50 per 1,000 board feet | Steel, 10 percent of cost of fabricated material | |
| Pyramid tower | 1 | 20 | Timber | 850 | 2,700 | $ 34.00 | $ 6.50 | — | $ 42.50 | — | $ 83.00 |
| Do. | - | 30 | do. | 1,400 | 4,500 | 56.00 | 8.75 | — | 70.00 | — | 134.75 |
| Do. | - | 40 | do. | 2,100 | 6,700 | 84.00 | 13.00 | — | 105.00 | — | 202.00 |
| Do. | 3 | 20 | Steel | — | 2,240 | - | - | $ 134.40 | — | $ 13.44 | 147.44 |
| Do. | - | 30 | do. | — | 3,660 | - | - | 219.60 | — | 21.96 | 214.56 |
| Do. | - | 40 | do. | — | 5,360 | - | - | 321.60 | — | 32.16 | 352.76 |
| Through tower | 2 | - | Timber | 1,250 | 4,000 | 50.00 | 7.00 | - | 62.50 | — | 119.50 |
| Do. | - | - | do. | 1,750 | 5,600 | 70.00 | 9.50 | - | 87.50 | — | 167.00 |
| Do. | - | - | do. | 2,300 | 7,400 | 92.00 | 15.00 | - | 115.00 | — | 222.00 |
| Tension Station | 4 | - | do. | 6,500 | 20,800 | 260.00 | 35.00 | - | 325.00 | — | 620.00 |
| Do. | 5 | - | Steel | - | 18,000 | - | - | 1,080.00 | - | - | 1,188.00 |

1/ Framing and erecting costs depend on availability and quality of skilled labor. Costs shown are based upon erection at reasonably favorable locations. On steep, rocky hillsides, the costs may greatly exceed those shown.

2/ Includes cost of structure only. Foundations, saddles, sheaves, etc. are extra.

Steel has certain advantages over timber, especially for permanent ystems. The fire hazard is eliminated almost completely. Furthermore, steel structure requires little if any attention after it is once built. ith timber structures constant vibration sometimes causes bolts to work oose and project in places where they are likely to foul passing carriers.

## Roofing

Corrugated roofing is the most economical and probably the most generally sed material for covering the roof and sides of terminals. It has virtually o insulating value and hence is a protection only against wind, rain, and now. Tramway terminals are difficult to heat because of incoming and outoing carriers; the writer knows of no instance where heating is attempted.

## Foundation Material

Concrete is by far the most satisfactory material for foundation piers. nchor bolts are more easily placed, and accuracy in alinement and elevation s possible with less effort than with stone masonry. The cost depends almost ntirely on the accessibility of the location where it is to be used. In laces where cement, gravel, sand, and water must be packed on animals, the ost may be as high as $15 or even more per cubic yard. In more accessible laces it may be little if any more than the cost of stone masonry. Timber ills sometimes are used but are generally unsatisfactory on permanent lines. ome very serviceable tramways were built with the towers on timber sill oundations, but it is doubtful if the lower cost compensates for the cost nd annoyance from towers settling out of alinement owing to uneven decay of he sills.

## Equipment

Tramway equipment other than cables comprises driving and control machinery, arriers, saddles, sheaves, and rollers, end and line couplings, attaching and etaching devices, and overhead rail for terminals and intermediate stations. anufacturers generally do not quote itemized prices on this equipment. It is enerally supplied at a gross contract price without regard to the cost of each ndividual item required for a job. Carstarphen[6/], however, gives the cost and eight of terminal machinery and tension station and line equipment, including arriers, required for tramways ranging in capacity from 25 to 100 tons per our. These data are shown in tabular form in Part I of Bureau of Mines, nformation Circular 6948, Aerial Tramways in the Metal-Mining Industry. For onvenience they are repeated here.

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/ Carstarphen, F. C., Aerial Tramways: Trans. Am. Soc. Civil Eng., vol. 92, pp. 875-973.

| Capacity per hour | Size cable, loaded side, inches | Size cable, empty side, inches | Size traction rope, inches | Couplings per mile | Capacity carriers, cubic feet | Spacing of carriers | Time interval, seconds | Number of carriers per mile | Number of supports per mile | Weight, in pounds per 100 feet | Cost per 100 feet | Terminal weight, pounds | Terminal cost | Tension station weight, pounds | Tension station cost | Gage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 1 | 7/8 | 1/2 | 4 | 5 | 300 | 36 | 37 | 20 | 1,017 | $144 | 26,400 | $2,894 | 7,300 | $733 | 6 |
| 30 | 1 1/8 | 7/8 | 1/2 | 4 | 6 | 300 | 36 | 37 | 22 | 1,127 | 155 | 32,700 | 3,540 | 7,800 | 766 | 8 |
| 40 | 1 1/8 | 7/8 | 1/2 | 4 | 6 | 225 | 27 | 48 | 22 | 1,191 | 172 | 32,700 | 3,540 | 7,800 | 766 | 8 |
| 50 | 1 1/8 | 7/8 | 1/2 | 4 | 6 | 180 | 21.6 | 59 | 22 | 1,256 | 189 | 32,700 | 3,540 | 7,800 | 766 | 8 |
| 50 | 1 1/4 | 7/8 | 5/8 | 5 | 12 | 360 | 43.2 | 32 | 22 | 1,348 | 184 | 38,900 | 4,154 | 9,100 | 900 | 8 |
| 100 | 1 1/4 | 7/8 | 5/8 | 5 | 12 | 180 | 21.6 | 60 | 22 | 1,625 | 243 | 38,900 | 4,154 | 9,100 | 900 | 8 |
| 100 | 1 3/8 | 7/8 | 5/8 | 6 | 15 | 225 | 27 | 49 | 22 | 1,703 | 240 | 38,900 | 6,087 | 10,100 | 1,005 | 8 |

## Cables - General Discussion

Cables must be discussed more comprehensively than any other tramway equipment; they are of primary importance in both the construction and operation of tramways. The wear on cables, and consequently the cost of replacement, is definitely affected by saddles and carriers and also by the arrangement of rollers and sheaves at terminals and towers. In view of this, it is difficult to discuss cables without at least touching upon the subject of certain other tramway equipment as well as upon general tramway design.

Cable costs for a continuous double-rope tramway of 20 tons capacity per hour will range from a minimum of about $3,500 per mile for comparatively flat and easy profiles to over $9,500 per mile for profiles requiring long spans and with great differences in elevation between terminals. Roughly speaking, the cable costs for any given profile will increase from $500 to $1,000 per mile for each 10-ton-per-hour increase in capacity. This, however, cannot be taken as a rigid rule for expressing cable costs in relation to capacity. The size of track cables required depends to some extent on the capacity of individual carriers and also on the speed of the traction cable. For instance, Carstarphen[7] specifies 1-1/8-inch cables for the loaded side and 7/8-inch for the empty side for tramways of 30-, 40-, and 50-ton-per-hour capacity, using carriers of 600-pound capacity. With 1,200-pound carriers, however, the cable size for the 50-ton capacity system is 1-1/4 inches for the loaded side. With profiles requiring long spans, the size of the track cables is likely to be

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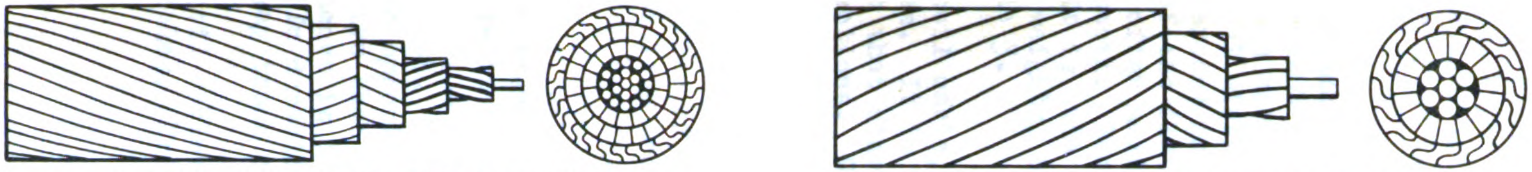
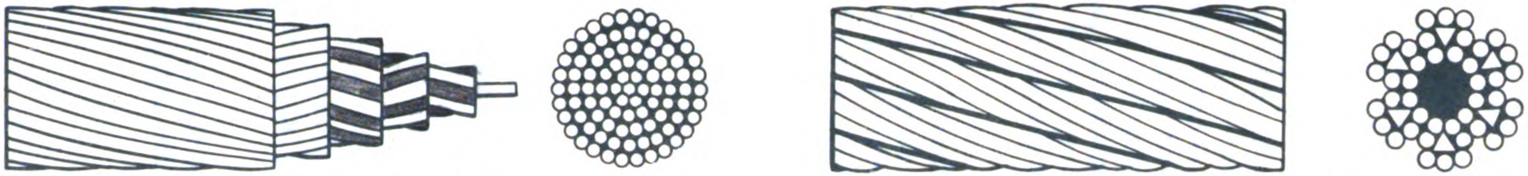
[7] Carstarphen, F. C., Aerial Tramways: Trans. Am. Soc. Civil Eng., vol. 92, pp. 875-973.



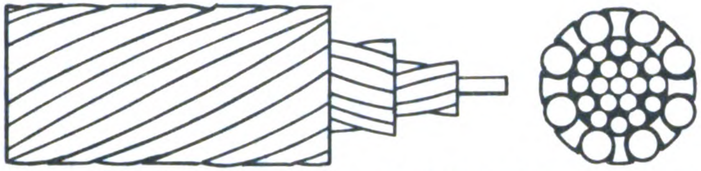
*A.* LOCK-COIL CABLE, TYPE A 83 WIRES

*B.* LOCK-COIL CABLE, TYPE B 34 WIRES



*C.* SMOOTH-COIL CABLE

*D.* FLATTENED-STRAND CABLE



*E.* LOCK-COIL CABLE, ENGLISH AND EUROPEAN TYPE

Figure 6.—Types of tramway track cables.

termined by permissible sag rather than by capacity of carriers.

A number of types of track cable have been developed by American and ropean cable manufacturers (fig. 6). A few of the more common types are scribed briefly here.

Flattened-strand cable of the 6- by 7-lang-lay construction is rec- mended by one American cable manufacturer as being superior in durability all other except the locked coil types. As with most stranded cables, e wire strands are built around a hemp core. Because of the large pro- rtion of metal wires to the total cross-section area, the tensile strength about 10 percent greater than for round-strand cables of the same diameter. e strands of the flattened-strand cable are fitted together in such a nner as to offer maximum resistance to crushing. The outside surface is latively smooth. Because of this, it wears better than the round-strand rieties. It is made in the same three grades as other strand cables. ices, unit weights, and tensile strengths for a number of sizes are own in table 3.

Smooth-coil cable, sometimes called tramway strand, is made entirely round wires. It is built up similarly to a single strand of a stranded ble, except that consecutive layers of wires (fig. 6, C) are twisted in posite directions. Unlike locked coil cables, different sizes are made of different numbers of wires. Thus, in the 1-inch diameter there are , in the 1-1/8-inch, 37, and in the 1-5/8-inch, 61 wires. Because of e fact that it is made up entirely of round wires, the tensile strength about 15 percent greater than that of locked-coil cable of the same ameter and grade of material. It is inferior, however, to locked-coil ble in durability and has the objectionable feature of the outside wires twisting when broken.

The type of locked-coil cables used commonly in the United States is de up of a center core of 7 or 19 round wires, one or more layers of res of square or trapezoidal cross section, and an outside layer of lock res. Figure 6, A and B, shows this type of cable in the 34-and the 83- re construction. As with smooth-coil cable, consecutive layers of wires e twisted in opposite directions. The locking feature of the lock wires more positive than in any other type. The cable has a smooth external rface and hence is less damaging to carriage wheels and saddles than any her type. In durability and wearing qualities it is superior to any other pe of tramway track cable.

Locked-coil cables and smooth-coil cables are made in cast-steel and ow-steel grades. Prices, unit weights, and tensile strengths are shown table 3.

### TABLE 3. - Properties and costs of tramway cables

(Prices and discounts furnished by A. Leschen & Sons Rope Co., St. Louis, Mo.)

| Class | Service | Construction | Diameter, inches | Cast steel | | | Special cast steel | | | Plow steel | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Weight per foot, pounds | Ultimate strength, tons | Price per foot | Weight per foot, pounds | Ultimate strength, tons | Price per foot | Weight per foot, pounds | Ultimate strength, tons | Price per foot |
| 1 | Traction | 6 by 7 lang lay | 1/2 | 0.38 | 7.5 | $0.09 | 0.38 | 8.2 | $0.105 | 0.38 | 9.0 | $0.125 |
| | do. | do. | 9/16 | .48 | 9.4 | .115 | .48 | 10.3 | .135 | .48 | 11.3 | .1625 |
| | do. | do. | 5/8 | .59 | 11.5 | .135 | .59 | 12.6 | .16 | .59 | 13.8 | .19 |
| | do. | 6 by 19 lang lay | 3/4 | .90 | 16.8 | .205 | .90 | 18.7 | .24 | .90 | 20.6 | .28 |
| | do. | do. | 7/8 | 1.23 | 22.8 | .25 | 1.23 | 25.4 | .29 | 1.23 | 28 | .345 |
| | do. | do. | 1 | 1.60 | 29.5 | .31 | 1.60 | 33.0 | .37 | 1.60 | 36.5 | .43 |
| 2 | Track | 6 by 8 flattened strand | 7/6 | 1.39 | 24.0 | .275 | 1.39 | 26.5 | .35 | [1] 1.39 | 33.2 | .44 |
| | do. | do. | 1 | 1.80 | 31.0 | .35 | 1.80 | 34.0 | .45 | [1] 1.80 | 43.0 | .58 |
| | do. | do. | 1-1/8 | 2.28 | 39.0 | .45 | 2.28 | 43.0 | .54 | [1] 2.28 | 54.0 | .70 |
| | do. | do. | 1-1/4 | 2.81 | 48.0 | .54 | 2.81 | 52.0 | .68 | [1] 2.81 | 65.0 | .88 |
| | do. | do. | 1-3/8 | 3.40 | 57.0 | .64 | 3.40 | 62.0 | .80 | [1] 3.40 | 79.0 | 1.08 |
| | do. | do. | 1-1/2 | 4.05 | 67.0 | .75 | 4.05 | 74.0 | .93 | [1] 4.05 | 93.0 | 1.28 |
| 3 | do. | Smooth coil, 19 wires | 7/8 | 1.55 | 37.6 | .299 | - | - | - | 1.55 | 44.4 | .343 |
| | do. | do. | 1 | 1.98 | 49.2 | .382 | - | - | - | 1.98 | 58.0 | .440 |
| | do. | Smooth coil, 37 wires | 1-1/8 | 2.58 | 60.0 | .462 | - | - | - | 2.58 | 70.7 | .508 |
| | do. | do. | 1-1/4 | 3.10 | 71.8 | .550 | - | - | - | 3.10 | 84.6 | .639 |
| | do. | do. | 1-3/8 | 3.79 | 88.8 | .694 | - | - | - | 3.79 | 105.0 | .790 |
| | do. | do. | 1-1/2 | 4.55 | 108.4 | .953 | - | - | - | 4.55 | 127.5 | 1.045 |
| 4 | do. | Locked coil, 34- and 83-wire types | 7/8 | 1.92 | 32.0 | .49 | - | - | - | - | - | - |
| | do. | do. | 1 | 2.50 | 42.0 | .64 | - | - | - | - | - | - |
| | do. | do. | 1-1/8 | 3.16 | 54.0 | .79 | - | - | - | - | - | - |
| | do. | do. | 1-1/4 | 3.91 | 65.0 | .95 | - | - | - | - | - | - |
| | do. | do. | 1-3/8 | 4.73 | 78.0 | 1.12 | - | - | - | - | - | - |
| | do. | do. | 1-1/2 | 5.63 | 93.0 | 1.[illegible] | - | - | - | - | - | - |

TABLE 3. – Properties and costs of tramway cables (cont'd)
(Prices and discounts furnished by A. Leschen & Sons Rope Co., St. Louis, Mo.)

| Class | Grade | Eastern territory, percent | Western and Pacific, percent | Eastern Montana, Utah, and Arizona, percent |
|---|---|---|---|---|
| 1 | Cast Steel | 15-10-5-5 | 10-10-5-5 | 5-10-5-5 |
| 1 | Special cast steel | 22-1/2-10-5-5 | 17-1/2-10-5-5 | 12-1/2-10-5-5 |
| 1 | Plow steel | 30-10-5-5 | 25-10-5-5 | 20-10-5-5 |
| 2 | Cast steel | 15-10-5-5 | 10-10-5-5 | 5-10-5-5 |
| 2 | Special cast steel | 22-1/2-10-5-5 | 17-1/2-10-5-5 | 12-1/2-10-5-5 |
| 2 | "Hercules" plow steel | 15-10-5-5 | 10-10-5-5 | 5-10-5-5 |
| 3 | Cast steel | No data | No data | No data |
| 3 | Plow steel | do. | do. | do. |
| 4 | Cast steel | 10 f.o.b. St. Louis | 10 f.o.b. St. Louis | 10 f.o.b. St. Louis |
| 4 | Plow steel | No data | No data | No data |

The English and European type of locked-coil cable shown in figure 6 is little used in the United States. A description of track cables, however, would be incomplete without some mention of it. It was made by several American manufacturers a number of years ago but at present is made principally in England. It is sometimes referred to as half-lock cable because only half of the outside layer of wires are lock wires; the others are round. Because of the greater number of round wires, it has slightly greater tensile strength than the type previously described. It is less durable, however, because of its stiffness and tendency to break from bending stresses.

The amount of service that can be expected from a track cable depends on a number of conditions, some of which are of a controversial nature. The most obvious, although by no means the most important, is the question of cable tension. Cable manufacturers, tramway builders, and tramway engineers disagree as to the tension at which a track cable should be operated to give the best service. Durham[8] suggests a safety factor for locked cables of 3-1/2 or a tension of 28-1/2 percent of ultimate strength. Recommendations of other authorities, principally cable and tramway manufacturers, range from 25 to probably as much as or more than 35 percent of ultimate strength. Experienced and successful tramway foremen sometimes operate tramways with the track cables at a lower tension than is generally recommended. It is not suggested that this practice should be followed generally, but the success of certain operators who do follow it and the service they get from the cables are matters that cannot be disregarded entirely.

The ratio of cable tension to concentrated load is another matter open to controversy. Considering the lack of agreement on the question of tension only, it is natural that this should be. Stresses due to bending of the cable at the point of loading are obviously proportional to the ratio of the concentrated load to the cable tension. Bending results in elongation or tensile stresses at the outside of the bend and compression or compressive stresses at the inside. Total tensile stresses at the bend are those due to bending plus those due to tension in the cable. The ratio of concentrated load to cable tension should therefore be such that the total tensile stresses at the bend are minimum. The determination of this ratio, however, and the calculation of cable size best suited for any concentrated load probably is far from a mathematically exact process. The reason for this is that a cable acts very differently in bending than does a solid rod or cylinder. The wires adjust themselves in such manner as to result in only a fraction of the tensile and compressive stresses that occur in a solid medium under the same conditions. Furthermore, cables of different construction have different bending characteristics. If this were not so, it would be pointless and futil to make cables of different degrees of flexibility for different kinds of service. If calculations are to be used at all, they should be interpreted in the light of practical experience.

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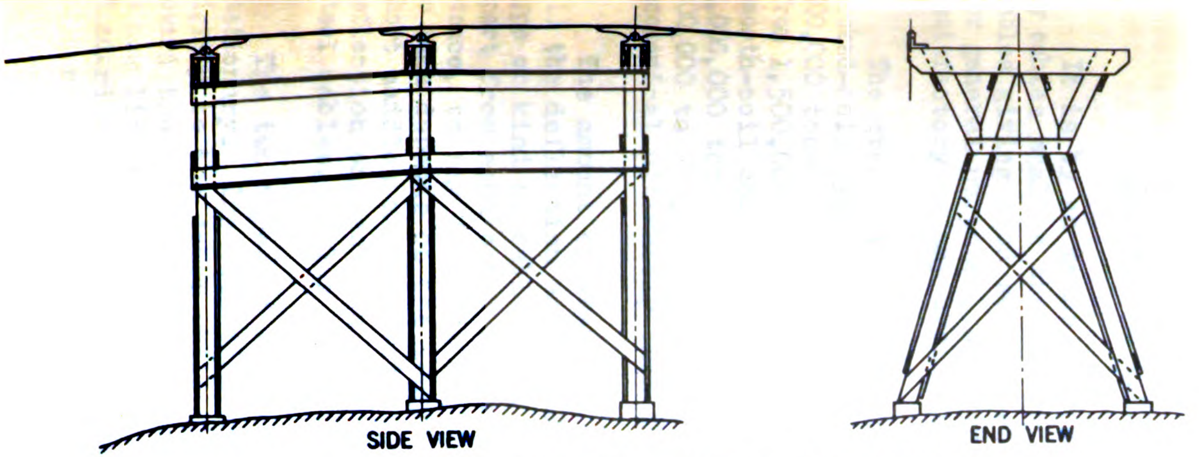
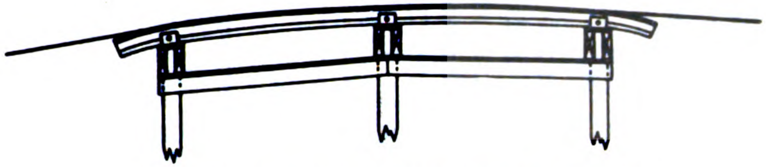
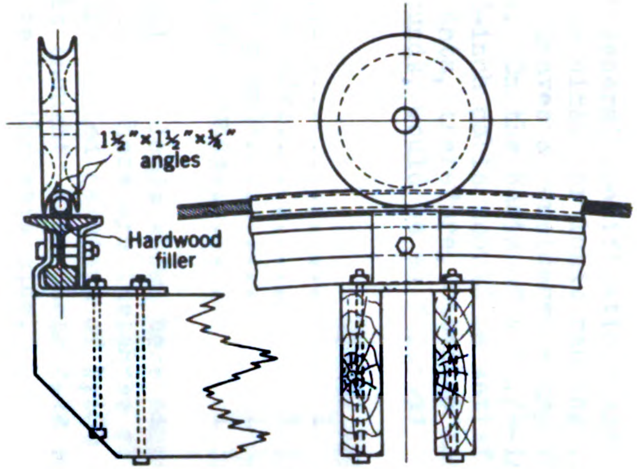
[8] Durham, Edward B., Aerial Tramways and Cableways: Mining Engineers Handbook, by Peele, 2d ed., vol. 2, ser. 26, p. 1745.



Track cables supported by rocking saddles



Track cables supported by continuous grooved rails made from inverted 90-pound railroad rail



Assembly details of 90-pound rail, angle irons, and bracket for fastening to saddle beam

Figure 7.–Track cable supports, rocking saddle, and continuous grooved rail.

Carstarphen[9] in his tables of general specifications and costs of ramway equipment (p. 8) shows cable sizes for loads ranging from 500 to ,500 pounds. The table, however, leaves a considerable gap for loads etween 600 pounds and 1,200 pounds. On the basis of a 1 1/4-inch cable or a load of 1,200 pounds, a 1 1/8-inch cable should be satisfactory for oads up to about 900 pounds. The data, therefore, extended and modified o include all loads up to 1,600 pounds, would be as follows:

| | Cable, inches |
|---|---|
| Loads up to 500........................ | 1 |
| Loads from 500 to 900 pounds............ | 1 1/8 |
| Loads from 900 to 1,200 pounds.......... | 1 1/4 |
| Loads from 1,200 to 1,600 pounds........ | 1 3/8 |

It is by no means contended that the loads shown here cannot be carried y cables smaller than those indicated. There are instances of 1 1/4-inch ables giving good service with four-wheeled carriers of 1,600 pounds capacity. or general purposes, however, it is thought that these data are about as atisfactory as any available and are on the safe side.

The greatest wear on the track cables is invariably at the towers. The ocked-coil types ordinarily can be expected to give a duty of 250,000 to 00,000 tons at the point where abrasive wear and bending are most severe and rom 1,500,000 to 3,000,000 tons on the long spans. Flattened-strand and mooth-coil cables, on the other hand, seldom give a service of more than ,000,000 tons under the most favorable conditions, and generally only from 00,000 to 750,000 tons. Although the first cost is lower, they are less conomical ultimately than the locked-coil types.

The amount of wear and breakage at a tower depends on three factors - 1) the deflection angle, (2) the length and design of the saddle, and (3) the ype or kind of cable used. These three factors cannot be discussed logically part from each other because they are interdependent. It is unsafe, for instance, to say just how small or how large a deflection angle may be, because o much depends on the length of the saddle and the kind of cable used. With hort saddles and plow-steel cables it probably is advisable to keep the eflection angles down to 3 1/2° or 4°. With 4-foot rocking saddles and cast-teel cables, angles up to 6° or even larger may be permissible.

The two types of saddles used most generally are the rocking and the tationary. The essential difference is that the stationary type is fixed igidly to the tower while the rocking type is pivoted on an axis and tilts oward the load as it approaches and leaves the tower. The stationary saddle s now little used except on old tramways. Rocking saddles are available as tandard tramway equipment and can be purchased from almost any of the American uilders of tramways. Track cables supported by rocking saddles on a three-ent support are shown in figure 7.

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/ Carstarphen, F. C., Work cited in footnote 7 (p. 10).

A third type of saddle is the continuous-grooved rail sometimes used on rail structures as well as on common supporting towers. It differs from the ordinary stationary saddle, first, in that it is longer and requires more than one point of support in fixing it to a tower and, second, in that the cable lies in a deep groove so that the carriage wheels are not in contact with the cable when the carriage is on the rail; a filler of hardwood or other material in the bottom of the groove eliminates excessive abrasive wear on the cable. It is used occasionally on heavy-duty tramways but seldom on trams of moderate capacity.

Although variations of continuous grooved rails have been used to a limited extent for many years, it is doubtful if they can be obtained as standard equipment. They can be built, however, at any mine that has the ordinary mine-shop facilities. Slight variations in design are possible. The design shown in figure 7 was developed by Charles A. Chase, manager of the Shenandoah Dives Mining Co. of Silverton, Colo., for use on the Shenandoah Dives tramway. This line originally was equipped with ordinary standard rocking saddles, which were not entirely satisfactory. Substitution of the grooved rails eliminated much of the excessive tract cable wear at the towers.

Any stranded cable of lang-lay construction and enough flexibility and strength is suitable for traction purposes. The 6 by 7 round-strand construction generally is used in sizes up to 1/2 or 5/8 inch diameter and the 6 by 19 construction in larger sizes. Special types having small wires in the inside of the strands and large wires on the outside have been developed to give a maximum of flexibility and wearing qualities. Nearly all stranded cables are made in four grades - cast steel, special cast steel, plow steel, and special plow steel. Prices, unit weights, and tensile strengths for various sizes in each grade are given in table 3. The cast-steel grades are the most satisfactory as they are more flexible and pliable than the plow-steel grade, and hence permit of a better gripping action in attaching the carriers. The plow-steel grade, however, is sometimes used where more than usual tensile strength is required.

Proper care of tramway cables is necessary if long life and maximum service are to be expected. Both track and traction cables should be kept thoroughly lubricated when in use. A lighter and more fluid oil is used on tramway cables than on hoisting cables. It can be applied to the traction cable at the terminals, but a special oiling device must be used for the track cables. One satisfactory arrangement consists of an oil tank fixed to a carriage. The tank is filled partly with oil and partly with compressed air. As the carriage runs over the line the compressed air forces the oil through a small spigot onto the track cable.

Next to lubrication, the most important matter to be considered in connection with traction cables is that of sheaves and rollers. Since wear on the cable is due largely to its passing around sheaves, it is obvious that the few and larger the sheaves used, the less will be the wear. Besides the grip or drive sheaves at the control station and the main sheaves at other stations an the main sheaves at other stations and terminals, a number of idler sheaves or rollers are always necessary to deflect the cable to the proper position for attaching and detaching carriers. The angle of contact with most idler sheaves is very small, hence the amount of wear they cause is negligible. The number and arrangement of sheaves required in attaching a movable tension weight is almost entirely a matter of terminal or control-station design. Perhaps the most satisfactory arrangement is the one whereby the cable passes around one large horizontal sheave mounted on a slide, on which it moves foreward and back in taking up the slack. A tail cable reaches from the sheave to the movable tension weight. It may sometimes be necessary for this cable to pass around several sheaves. The wear on it, however, is not great because of the relatively small amount of movement. It can be replaced at a very low cost because usually it is not more than 50 to 100 feet in length. With other arrangements, the main traction cable passes around as many as seven main sheaves besides the small ones required to deflect the cable away from the carrier grips at the attachers and detachers.

The excess tension developed in the traction cable when a carrier enters a break-over tower and the means of overcoming it by the use of overhead rollers are discussed in Part 1.[10] In certain specific instances where overhead rollers were not used, the excess tension in the traction cable and the strain on the carriers was great enough to pull the carrier bails out of shape and even break the carriage wheels.

Overhead rollers on rail sections or break-over towers, especially on the loaded side where the tension is greatest, sometimes are placed as close together as space will permit. The object of this practice is to make the angle of contact of the cable with each roller as small as possible and to distribute the weight due to tension in the cable over as many points as possible.

The amount of wear on the traction cable produced by such a battery of rollers is a matter of some controversy. The practice is followed by at least one of the largest cable and tramway manufacturers in the United States. Some tramway operators, on the other hand, believe that less wear will result if the traction cable is supported by large sheaves placed below the carriers instead of by rollers placed just below the grips. Carriers with extra strong bails and carriages are used to take care of the excess tension developed.

## Erection and Installation Costs

Erection and installation include the cost of excavating and building foundations, framing and erecting structures, stringing cables, installing machinery, and many other miscellaneous items. These are mostly labor and supervision costs, although other costs, such as trucking, teaming, packing, equipment for stringing cables, and material for erecting temporary buildings also are involved.

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[10] Metzger, O. H., Aerial Tramways in the Metal Mining Industry, Part 1: Bureau of Mines Inf. Circ. 6948, 1937, 32 pp.

It is in erection and installation that estimates of construction costs are most likely to be in error. Estimates for jobs in isolated regions of rough topography should never be made without first examining each structure location carefully. Material must often be carried by pack animals or even lowered over cliffs by hand to the places where it is to be used. In many places trails, temporary roads, and temporary quarters for workmen must be built. Failure to consider any or all of these items may result in a considerable error in the final estimate. The cost of trail building for the tramway of the Premier Silbak Mines, Ltd., of Premier, British Columbia,[11] was $7,352, or approximately 2 percent of the total construction cost of $360,000. Temporary quarters cost $5,457, or approximately 1-1/2 percent of the total. These costs in this particular instance are of relatively little importance, as together they comprise only 3-1/2 percent of the total. There are instances, however, in which they amount to much more than this.

Stringing and installing cables is a job that requires the services of a specialist and generally some special equipment. Cable installation costs on the Premier tramway were $16,168, or $1,400 per mile; on the Porter, (Idaho) tramway of the same company they were $7,377, or $1,475 per mile.

Trucking, teaming, and packing costs depend entirely on accessibility of structure locations. Team hauling for construction of the Premier tramway cost $24,172, or $2,100 per mile. At the Porter, (Idaho) tramway, where structure locations were more difficult of access, the cost of handling and transporting equipment was $62,039, or $12,200 per mile.

Fabricated steel costs two to three times as much as unframed timber. According to Staley,[12] the framing and erecting costs of timber for small timber head frames should be around $30 per thousand board feet. This is on a basis of erecting on level ground under reasonably favorable conditions. On steep, rocky hillsides, where working conditions are less favorable, erecting costs are higher.

## Underground Construction

The practice of running tramway carriers through adits to underground loading stations was little applied in the metal-mining and other industries until relatively recent years. Even at present, there are only a few isolated examples of important underground installations on the North American Continent. The possibility, however, of substantial savings being made in underground haulage and handling of ore by this means seems to warrant some discussion.

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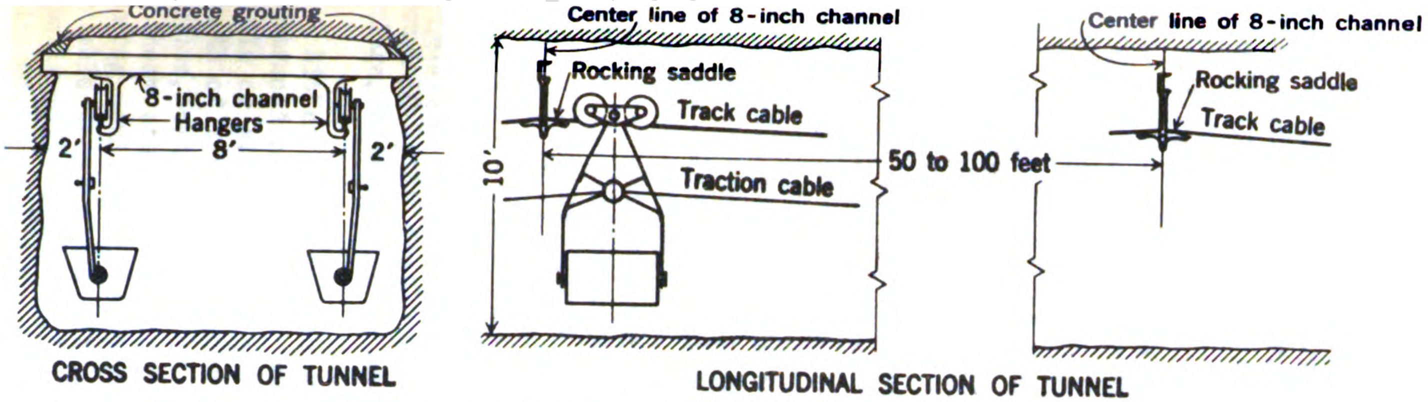
[11] Pitt, Dale L., Work cited in footnote 4 (p. 3).

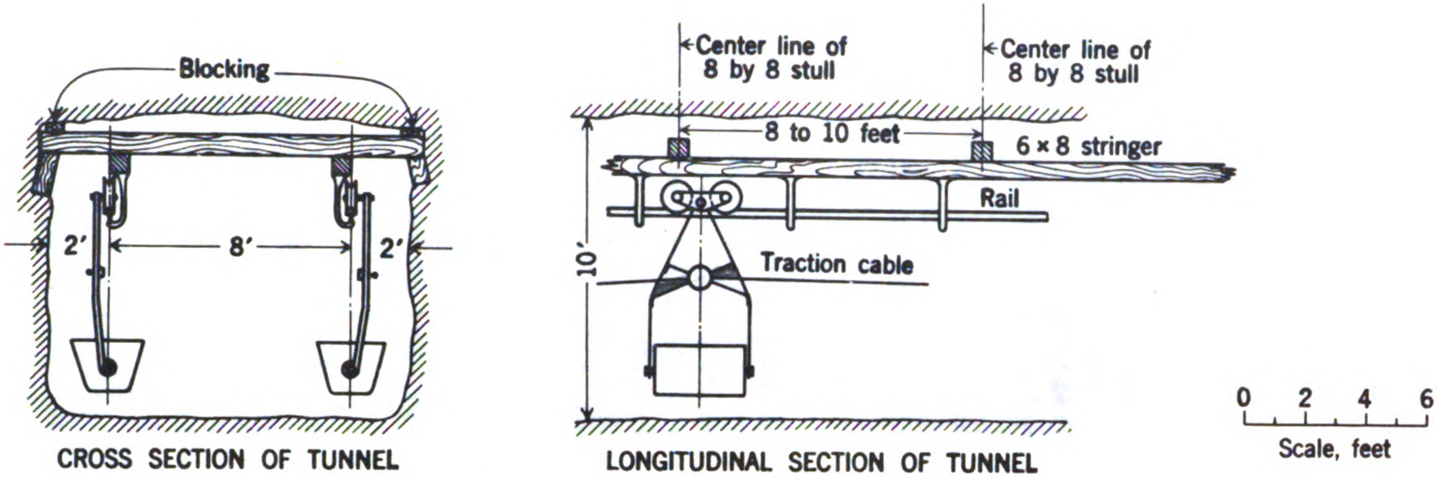
[12] Staley, W. W., Design of Small Wooden Head Frames: Bureau of Mines Inf. Circ. 6943, 1937, 37 pp.



CROSS SECTION OF TUNNEL

LONGITUDINAL SECTION OF TUNNEL

TRACK CABLE SUSPENSION FOR USE IN ADIT TUNNELS
(8 by 8 or 8 by 10 stulls can be used in place of 8-inch channels)



CROSS SECTION OF TUNNEL

LONGITUDINAL SECTION OF TUNNEL

RAIL SUSPENSION FOR USE IN UNDERGROUND TERMINALS
(channels or I-beams can be used in place of 8 by 8 stulls
and 6 by 8 stringers)

Figure 8.—Underground construction details.

Obviously, the use of aerial tramway carriers for transporting ore through long adits is practical only where surface transportation is by aerial tramway. In such places it may sometimes be found feasible and advantageous to load the carriers from an underground ore pass or transfer station and thus eliminate underground motor haulage and rehandling of ore at the portal. In general, this would be practical at any plant where surface transportation is by tramway and underground transportation through a straight adit. Actually, however, there are only a few isolated instances where the practice is justified.

Ordinarily, only straight crosscut adits can be equipped for this purpose. Horizontal angles, however, are permissible to about the same extent as for surface lines, provided that the parts of the adit between angles are perfectly straight. Drift adits, on the other hand, could rarely be used, because they are seldom straight for more than a few hundred feet. Character of ground is another feature that must be given careful consideration. No form of underground tramway installation should be considered in ground that does not stand well without timbering. Where motor haulage is used, a certain amount of repair work can be, and often is, done while haulage is in progress. This is possible because of the intermittent nature of motor haulage. It would be impossible, however, where a traction cable and tramway carriers are continually in motion.

An adit for an 8-foot-gage tramway would have to have a minimum width of about 14 feet. The gage, however, can be drawn down to 6 or even 4 feet where the cables enter the adit. For the 6-foot gage, the adit should be about 12 feet wide, and for the 4-foot gage, 10 feet wide. Most tramway carriers of moderate capacity measure about 7 feet from the top of the carriage wheels to the bottom of the bucket. Allowing for a clearance of foot below the bucket and a space of 2 feet above the top of the carriage wheels for placing a timber stull or steel channel on which to fix saddle beams or overhead rail hangers, the height required would be around 10 feet. If there is much cable sag or deflection it would have to be more, therefore, the minimum size of an adit required for tramway transportation would be around 10 by 10 feet. This compares favorably with adits required for motor haulage, although it is higher than is ordinarily required.

Either track cables or overhead rails can be used for carrier tracks. Construction is simpler and no doubt more economical with cables. Horizontal stulls or steel channels set at the proper height and at right angles to the ength of the tunnel generally are the only members required for attaching addles, saddle beams, or hangers (fig. 8). If cables are used, the spacing f these stulls or beams need not be closer than 50 to 100 feet; the minimum pacing would be determined by the permissible sag, which in turn is determined y cable tension and weight of loaded carriers. If overhead rails are used the pacing must be closer, - 10 feet or less - and construction slightly more complicated.

On a basis of 50-foot spacing the cost of 8- by 10-inch select timber tulls per 1,000 feet of tunnel would range from $55 to $80, while the cost f 8- by 2-1/2-inch channels would range from $120 to $180. Since the cost in either instance is only a small percentage of the total cost of all the equipment required, there would be little or no justification for using timber. Steel channels can be placed best by concreting them in a hitch in the proper location near the top of the adit; timber beams, by wedging them in a hitch and blocking the ends from the top. The labor costs should be about the same for each.

The total cost of equipping a tunnel for aerial tramway transportation should range from $1,000 to $2,500 per 1,000 feet or from $5,280 to $13,000 per mile. Compared to this, the cost of equipping for underground motor haulage is negligible. In fact, a tunnel must be equipped for motor haulage while it is under construction. The only saving in construction costs effected by running tramway carriers to an underground loading station is in the elimination of a loading terminal, including bins, at the tunnel portal. Savings in operating costs might be considerable however, because of the elimination of motor haulage and the rehandling of ore.

The tramway of the San Francisco Mines of Mexico, Ltd., at San Francisco del Oro, Chihuahua, Mexico, is the only important underground installation on which pertinent data are available. This system is described in the Engineering and Mining Journal[13] for August 1936.

The underground portion of this tramway is 931 meters (3,054 feet) long. It extends from an angle and control station near the tunnel portal to the underground loading station. The tunnel is 3-1/2 meters high by 4 meters wide (11.5 by 13.1 feet). The track cables, 1-1/2-inch and 7/8-inch locked coil, are supported by rocking saddles suspended from 8-inch channels cemented into the rock at 30-meter (98-1/2-foot) intervals. Tension in the track cable on the loaded side is maintained at 30 tons by a concrete weight. The carriers have a capacity of 1 metric ton (2204.6 pounds) and a gross weight of 1,200 kilograms (2,651 pounds). The center deflection between supports due to the loads is about 0.25 meter (0.82 foot). The carriers are spaced close enough so that rollers are not required to keep the traction cable from dragging on the bottom of the tunnel.

## Types of Tramways, Comparative Costs

Three types of tramways - double-rope continuous, reversible or jig back, and monocable - are described in Information Circular 6948, Aerial Tramways in the Metal-Mining Industry, Part I. Of these, the double-rope continuous type is the most costly but also the most adaptable to steep grades, rough and varying topography, and long distances. It is the type most generally used in Alaska, Canada, the United States, and Mexico. The reason for this is obvious when it is considered that in these countries aerial-tramway transportation usually is resorted to only in places where the topography is so rough that other methods are impractical.

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[13] Campbell, W. G.: Eng. and Min. Jour., vol. 137, No. 8, August 1936, pp. 391-396.

Reversible or jig-back tramways often are used where physical conditions are favorable. Since there are only two carriers, the carrying capacity decreases as the length increases. A fairly uniform grade is desirable but not essential. Variations in grade can be overcome by using a tail cable that passes around a sheave at the discharge terminal. Cable costs are only slightly if any less than for double-rope continuous systems. Terminals, however, are much less complicated and costly, especially where either terminal is built on a steep hillside. The carriers can be loaded and unloaded without bringing them to a horizontal floor, thus eliminating the necessity of a costly curved-rail assembly, such as must be built at the end of hillside loading terminals for continuous double-rope tramways. Generally, one man does the loading and operates the drive or control machinery. Dumping or unloading is done by an automatic tripping device at the discharge terminal or by a mechanism attached to one of the carrier wheels, which unlatches an end or side gate of the carrier when the direction of travel is reversed. Tramways of this type having capacities from 100 up to 150 tons per hour are in use in the coal-mining and limestone-quarrying industries.

Monocable systems are little used in the United States, Canada, or Alaska. Exhaustive inquiry revealed only one important tramway of this type in use in the metal-mining industry on the North American Continent. There may, however, be others. Although the first cost is less, monocable tramways have found little favor with American tramway engineers and manufacturers. The reason for this, as already explained, is that they are less adaptable to rough topography and steep grades than other types. The application and limitations of this type are discussed in Part I.

## OPERATING COSTS

Operating costs may be considered under the following classifications: Power; supervision; labor; repairs; replacements; and depreciation.

### Power

A large percentage of the tramways used in metal-mining operations are used for transporting ore or concentrates on a downgrade only. In such cases a motor is used as a brake and actually puts current back into the line. An induction or a slip-ring motor acts as a generator by running above synchronous speed; slip-ring motors generally are used because they have better speed control. If a synchronous motor is used in conjunction with a slip-ring motor, the speed of the system will be constant regardless of the load, because the synchronous motor will not run at a speed greater than that corresponding to the line frequency. A synchronous motor cannot be used alone, however, because it has no starting torque to overcome line friction in starting when both sides of the line are unloaded or in balance.

If current generated by a tramway can be utilized for other purposes, it is proper to credit the tramway accordingly and thus show a lower over-all operating cost. In practice, however, the tramway motor simply puts current back into line to be used for other mine equipment. The power developed by a tramway can be calculated easily if the frictional resistance is known.

This, however, cannot be used as a basis of giving a power credit because of starting, stopping, and short delays. To make a proper credit, the tramway motor should be metered independently.

Power cost on tramways that actually require power seldom exceeds 0.2 cent per ton-mile; in some instances it is less than 0.1 cent per ton-mile.

## Supervision

The salary of a tramway foreman generally comprises the entire supervision cost of operating a tramway. A man for this job should be capable of splicing cables, repairing couplings, and supervising all repair work. A first-class tramway foreman frequently is one of the highest-salaried men in a mine organization and may have the same salary rating as a mine or mill superintende

Supervision costs depend to a great extent on the amount of material handl Some large mining companies have two or more tramways under the supervision of one man. The Real del Monte of Pachuca Co. in Pachuca, Mexico, at one time ha four tramways in operation, all under the general supervision of one American foreman with three or four native assistants. The cost in this instance was very low. Supervision should cost not more than 1 cent per ton-mile for trams of moderate length and capacity. Generally, it costs less than this. At the Shenandoah Dives mine in Silverton, Colo., tramway supervision costs about three-fourths cent per ton-mile and at the Premier mine in Premier, British Columbia, about one-fourth cent per ton-mile. Both tramways are well-built and operated under good management. The difference in supervision costs per ton-mile is due to the fact that the Premier tramway is about five times the length of the Shenandoah Dives.

Tramways of limited length and capacity generally do not require an extra man for supervision. The duties of a foreman can be assumed by one of the tram operators, and repairs can be made by the master mechanic of the mine or mill. This, or similar arrangements, are sometimes necessary on small tramways to keep tramming costs equal with mining and milling costs.

## Labor

Labor costs generally are the largest single item involved in operating a tramway. The system that requires the least men to operate is the one that will have the lowest per-ton-mile cost. Most tramways at metal-mining plants are used for hauling back freight as well as ore. It is this feature of metal mine operating that often makes it impracticable, or at least inadvisable, to install automatic or semiautomatic trams at metal-mining plants. Tramway-operating costs at most metal mines in the western United States range from about 5 to 10 cents per ton-mile. In the coal-mining and construction indust of the eastern United States, tramming costs of 2 to 3 cents per ton-mile are uncommon, and costs as low as 1 cent per ton-mile are reported. The differen can be explained partly by the larger-capacity tramways used in coal mining a construction work, but also many of the tramways in these industries are auto or semiautomatic and require a minimum of labor in their operation.

The Pardee Dam tramway, length 3.1 miles, capacity 220 tons per hour, consisted of two sections with an intermediate control station. Carriers at terminals and the intermediate control station were handled largely by mechanical means. The carriers remained attached to the traction cable while passing through the discharge terminal and were unloaded while in motion. This tramway could be operated by five men - two at each terminal and one at the intermediate control station as a safety measure. More men than this may have been used; on a basis of five men per shift, however, the labor cost of running the tram would be about 1/2 cent per ton-mile.

The Highland Boy tramway, Bingham Canyon, Utah, capacity 100 tons per hour, is a hand-operated system. The total length is 4 miles. It consists of three sections, each of which is operated by a separate control system. When operating at full capacity, five men are required at the loading station, 2 at each of the two intermediate control stations, and 3 at the discharge terminal.

A comparison of these two systems, the one automatic and the other hand-operated, indicates that labor costs per ton-mile for the hand-operated system are approximately four times as great as for the automatic system, due partly to the larger capacity of the automatic system; if, however, it was operated at a reduced capacity equal to that of the hand-operated system, the labor costs would still be only about half that of the hand-operated system. Under actual operating conditions, labor costs for hand-operated systems probably are 2 to 3 times those of automatic systems.

Comparatively few automatic trams are in use in the metal-mining industry. One reason for this has already been mentioned - the necessity of hauling back freight. Another reason is that where wet ore is handled in cold climates, freezing would interfere seriously with the free dumping or unloading of the buckets and also with latching and unlatching of a bottom or end door.

The capacity of a hand-operated tramway sometimes is limited to the rate at which carriers can be handled at the terminals. When carriers enter a loading terminal at intervals of 20 seconds or less, it becomes difficult to take care of them by hand methods alone. If they are loaded and dispatched mechanically, however, they can be handled much more rapidly. At the Pardee Dam tramway it was found possible to load and dispatch carriers of 1-1/2-ton capacity in 4 to 5 seconds. The normal interval was 24-1/2 seconds and the rated capacity 220 tons per hour. The builders claimed that because of the ease with which carriers could be handled the capacity could be increased greatly by simply adding more buckets.

Two men is the minimum required to run a hand-operated tramway of the continuous double-rope type. For tramways having carrying capacities up to 20 tons per hour, one man must be stationed at the loading terminal and one at the discharge terminal. If the capacity is very much greater than this more men are required, especially at the loading terminal. Since the capital expenditures for a tramway of 20 tons per hour capacity are but little more than for one of 8 or 10 tons per hour, it is reasonable to assume that 20 tons per hour is about the low economic limit for tramways of the double-rope continuous type. It is granted that there are small metal-mining plants that do not require a tramway of 20 tons per hour capacity; but in this instance, a little extra bin capacity at the terminals is the only arrangement required to permit the tram to be operated every other day or 2 to 3 days per week instead of at full time. For temporary installations where a small increase in capital expenditures is likely to be a controlling factor, a double-rope, continuous tramway of less than 20 tons per hour capacity might be justifiable For permanent installation, however, it would seem uneconomical to consider a system of this kind of less than 20 tons per hour capacity. Where a small daily tonnage is to be handled and where physical conditions permit, it is better to consider a double-reversible or jig-back tram than a continuous one. The double-reversible tram requires about the same amount of cable as a continuous double-rope tramway, but the terminals cost less and only one man is required to operate it.

An important feature about tramways that greatly affects operating costs is the capacity of the carriers. This often is overlooked when a tramway is designed to deliver a certain daily tonnage. The number of men required at a terminal is determined to a great extent by the time interval between the arrival of buckets or the rate at which the carriers must be handled. For any given hourly tonnage it is obvious that with carriers of 1,200 pounds capacity, the time interval, and hence the number of men required to handle them, is only half what it would be with carriers of 600 pounds capacity. A larger track cable sometimes is required for the larger-capacity carriers. However, where the size of the track cable is determined by the permissible sag rather than by the weight of the concentrated load, there would seem to be little justification for using carriers of less than 1,000 pounds capacity. Even where this is not the case, the saving in cost of carriers would compensa in part at least, for the difference in price of the cables.

Operating costs of automatically operated tramways are affected little b wage rates. Probably the lowest tramming costs in the world have been made o automatically operated systems in the United States, where wages are the high in the world.

Labor costs of operating tramways at three metal mines in the United Sta and Canada are shown in the following table:

| Tramway | Location | Labor cost, cents per ton | | Percen of tot operat costs |
|---|---|---|---|---|
| | | Per ton transported | Per ton-mile | |
| Shenandoah Dives.. | Silverton, Colo. | 6.2 | 3.1 | 60 |
| Premier 1/ ......... | Premier, British Columbia | 56.1 | 4.9 | 63 |
| Peru.............. | Hanover, N. Mex. | 5.4 | - | 68 |

1/ Average of 5 years.

## Maintenance and Repair

Maintenance and repair costs include repairs on terminals, control stations, and line structures and also minor cable replacements. The stretch in the traction cables must be corrected for occasionally by cutting out a small section and then resplicing the cable. The cost of replacing small sections of track cable in places where the wear is excessive generally is carried as a current operating charge under maintenance and repair.

Minor cable replacements and other repairs that must be made from month to month fall quite naturally into current operating expenses. When a whole traction cable must be replaced, or when all or a large part of a track cable must be discarded and replaced, it is not so obvious how the cost should be distributed. Sometimes it is entered as a deferred charge against future operations, but generally it is charged to current operating expenses as maintenance or replacement.

There are very few available data concerning replacement costs of rolling stock, sheaves, rollers, and other tramway equipment. Replacement of these items generally is charged to current operating expenses as maintenance and repair. Terminal sheaves on the Kennecott tramway of Kennecott, Alaska, give a duty of about 1,000,000 tons and line sheaves of about 115,000 tons.

## Cable Replacements

The wear on traction cables is generally uniform throughout their length. Short sections must be replaced only in case of accidents that damage the cable in one particular place. Generally the cable is used until it is worn to a state that makes it unsafe; it is then discarded and replaced by a new one. The following tables show the performance of track and traction cables at a number of typical tramways and the cost of replacing on a basis of ton-miles.

## Depreciation

Actual depreciation charges against a tramway should be based upon the total tonnage transported by it during its lifetime. At metal-mining plants, however, it is seldom possible to predict, even approximately, the tonnage that must be handled ultimately; hence, it is difficult to make a correct depreciation charge against current operations. In practice it is customary to make relatively large depreciation charges against mining equipment during years of prosperity, and thus the total capital expenditure of a tramway may be charged off many years before it has served its full usefulness. Under such circumstances, actual depreciation costs seldom appear on company books.

Many tramways serve as surface transportation systems at metal-mining plants from the beginning of operation until the ultimate depletion of ore reserves. Others lose their usefulness many years before the depletion of ore reserves because they are supplanted by other systems, such as long haulage adits. From a study of many successful tramways used at metal-mining plants, the cost appears to range from $30,000 to $65,000 a mile. A great majority of these have transported more than a million tons of ore and some as much as 3 million tons. On this basis, the actual depreciation costs range from a minimum of 1 cent to a maximum of 6.5 cents per ton.

Major track cable replacement costs

| Tramway | Situation | Capacity per hour, tons | Cable, size in inches and type |  |  | Total tons trammed when replaced | Costs per ton-mile, cent |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Loaded side | Empty side | Type |  | Loaded side | Empty side | Total |
| Sunnyside | Silverton, Colo. | 40 to 50 | 1-3/8 | 1-1/8 | Locked coil cast steel | 1,500,000 to 2,500,000 | 0.22 to 0.35 | 0.15 to 0.25 | 0.37 to 0.60[1/] |
| Silver King | Park City, Utah | 40 | 1-1/4 | 1 | Flat-tened strand plow steel | Loaded side, 800,000; Empty side, 1,200,000 | .44 | .19 | .63[1/] |
| Kennecott | Kennecott, Alaska | 21 | 1-1/4 | 1-1/8 | Locked coil cast steel | 1,500,000 to 2,500,000 | .23 to .38 | .19 to .32 | .42 to .70[2/] |

[1/] Does not include freight costs.
[2/] Includes freight costs.

| Name of tram | Situation | Capacity, per hour, ton | Size traction cables, inches | Kind of steel | Difference in elevation of terminals, feet | Tons transported | Cost per ton-mile, cent |
|---|---|---|---|---|---|---|---|
| Premier | Premier, B. C. | 17 | 3/4 | Plow | [1] 1,300 | 375,000 | 0.44 |
| Shenandoah Dives | Silverton, Colo. | 55 | 7/8 | do. | 1,500 | 500,000 to 750,000 | .24 to .35 |
| Sunnyside | do. | 40 to 50 | 7/8 | Special cast | [2] 1,300 | 750,000 to 1,000,000 | .19 to .25 |

[1] 1 continuous traction cable for 11 miles of tramway.

[2] Tramway in 2 sections, each operated by a separate traction cable. Vertical distances between ends of lower section about 1,500 feet; upper section about 800 feet.

Depreciation and amortization costs on the Kennecott tramway of the Kennecott, Alaska, are as follows:

| | |
|---|---|
| Length of tramway | 2.86 miles |
| Total ore transported | 3,505,000 tons |
| Total cost of tramway | $105,519.76 |
| Cost per mile | 36,890.00 |
| Depreciation costs per ton | .030 |
| Depreciation costs per ton-mile | .011 |
| Amortization costs, 20 years at 6 percent, per ton | .041 |
| Amortization costs, 20 years at 6 percent, per ton-mile | .015 |

## DESCRIPTION OF INDIVIDUAL TRAMWAYS

The following descriptions of tramways are based upon information supplied by mine operators in Alaska, Canada, the United States, and Mexico.

### Kennecott

The Kennecott Copper Corporation had two tramways for transporting copper ore from its mines to the mill at Kennecott, Alaska. A single discharge terminal is used for both tramways. Since the two systems are of similar construction and have about the same construction and operating costs, only one, the Bonango tramway, will be described here.

The total length of this tramway is 2.86 miles. The country through which it passes is rugged and mountainous. The elevation of the loading terminal is 3,609 feet above that at the discharge terminal.

Terminal and line structures are entirely of timber with concrete foundations. The loading terminal is 24 feet wide by 98 feet long, with two mill bins of 175 and 325 tons capacity and a high-grade bin of 250 tons capacity. Unloading space for freight is approximately 24 by 8 feet. The discharge terminal is approximately 30 feet wide by 70 feet long, with 400 tons bin capacity and 12 by 40 feet loading space for timber and other mine supplies.

Line structures consist of 34 supporting towers of the through type, 8 break-over towers or rail sections, including 2 intermediate tension stations, and 1 angle or control station. The distance from the loading terminal to the control station is 6,305 feet and from the control station to the discharge terminal 8,705 feet. The tramway also is used for transporting timber and other supplies to the mine. Passengers may ride only by special permission.

Driving and control machinery comprises a 50-horsepower motor geared to an 8-foot grip sheave at the loading terminal and a 35-horsepower motor geared to an 8-foot grip sheave at the angle or intermediate control station. Total power developed by the tram probably is less than 20 horsepower.

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The track cable is of cast steel and of locked-coil construction; on the loaded side it is 1-1/4-inches and on the empty side, 1-1/16-inches in diameter. The traction cable is 3/4-inch in diameter, 6 by 7 lang-lay construction, and of plow steel; it is operated at a speed of 450 feet per minute. Tension in track and traction cables is maintained by weight boxes.

The carriers, spaced at 450 feet, have a capacity of 6 cubic feet or 725 pounds. On this basis, the carrying capacity of the tramway is approximately 21 tons per hour. The carriers are of the two-wheeled type and are equipped with Weber grips.

The tramway is operated two shifts per day and 363 days per year. Approximately 122,000 tons is handled annually. The labor required to operate the tramway two shifts is as follows:

| | | |
|---|---|---|
| Loading terminal: | 2 | men each shift loading and sending out buckets, |
| Control station: | 1 | man each shift sending out buckets. |
| Discharge terminal: | 1 | man each shift dumping and sending out buckets; |
| | 1 | lineman, 1 shift only, greasing and inspecting tramway; |
| | 1 | foreman looking after 2 trams. |
| Total 2 shifts | 10 | |

The cost of operating the tramway, including labor, paint, lubrication, repairs, and bucket replacements, has averaged $6.27 per hour. Track cables at the break-over structures, where the wear is greatest, give a duty of about 230,000 tons; on the long spans, up to 3,000,000 tons. The duty of the traction cable is around 230,000 tons, terminal sheaves 1,000,000 tons, and line sheaves 115,000 tons.

The cost of the track cables on the loaded and empty sides is $1.08 er foot and $0.90 per foot, respectively; the traction cable is $0.18 per oot. Assuming a duty of 1,500,000 to 2,500,000 tons for the track cable n long spans and 230,000 tons for the traction cable, replacement costs ould be as follows:

| | Cents per ton-mile |
|---|---|
| Track cable, loaded side: | 0.23 to 0.38 |
| Track cable, empty side........ | .19 to .32 |
| Total track cables........ | .42 to .70 |
| Traction cable................. | 0.83 |
| Total track and traction cables | 1.25 to 1.53 |

Total costs, including operation, liquidation of capital investent, and 20 years amortization at 6 percent, are as follows:

| | Per ton | Per ton-mile |
|---|---|---|
| Total operating........................ | $0.300 | $0.109 |
| Tramway cost $105,519.76................ | .030 | .011 |
| 20 years' amortization at 6 percent..... | .041 | .015 |
| Total............................ | .371 | .135 |

## Premier[14]

The Premier tramway of the Silbak Premier Mines, Ltd., is in the vicinity of Stewart, British Columbia, and Hyder, Alaska. It extends from the Premier dock at the head of the Portland canal in British Columbia to the Premier mine about 9 miles due north. The tramway, however, follows a route 11.5 miles long that roughly parallels the Salmon River in Alaska. This route was followed in preference to a direct route because it avoided, a high mountain range lying between the Bear River in British Columbia and the Salmon River in Alaska. (fig. 9.) The line enters Alaska just north of Hyder and follows the Salmon River for nearly 10 miles before reentering British Columbia. The lower terminal is at tidewater, the upper one 1,300 feet above sea level.

Three angle stations were required for the route selected. The angles included between adjacent sections of the tramway are 81°25', 153°45', and 133°00'. The total of the horizontal deflection angles is 171°50'. Each angle station consists of a building approximately 150 feet long by 20 feet wide and 30 to 35 feet above the ground. One continuous traction cable is used for the whole system. It passes around smooth sheaves at the angle stations and the discharge tunnel and around a grip sheave at the loading terminal where the control machinery is situated. The carriers are run through the angle stations on rails, being automatically ungripped and gripped from the traction cable as they enter and leave.

The lower terminal is built on piling adjacent to a dock. It has a bin capacity of 1,500 tons and enough space for handling supplies sent to the mine. A 24-inch conveyor belt is used for conveying the ore from the bins to boats and scows. An incline provided with a hoist and car track is used in transferring freight from the dock floor to the terminal floor.

Besides the angle stations already mentioned, there are 163 line structures, consisting of 3 double-anchor stations, 1 double-tension station, 7 combination tension and anchor stations, and 152 towers of the pyramid type. All three angle stations serve as either tension or anchor stations. Track cable sections are anchored at one end and weighted at the other. All structures, including terminals, are of timber construction. Dimensioned timber was used for all but a few structures that were difficult of access; here, round or hewn timbers were used.

When the tramway was first built in 1921, 7/8-inch locked-coil track cable was used on the empty side and 1-inch on the loaded side. The traction cable was 5/8-inch cast steel and was run at a speed of 500 feet per minute with carriers of 8-cubic-foot or 850-pound capacity spaced at 1,000-foot intervals. With this set-up, the carrying capacity of the tramway was approximately 12.5 tons per hour. Later on the output of the mine was increased, and the capacity of the tramway had to be increased accordingly.

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[14] Pitt, Dale L., Work cited in footnote 4 (p. 3).

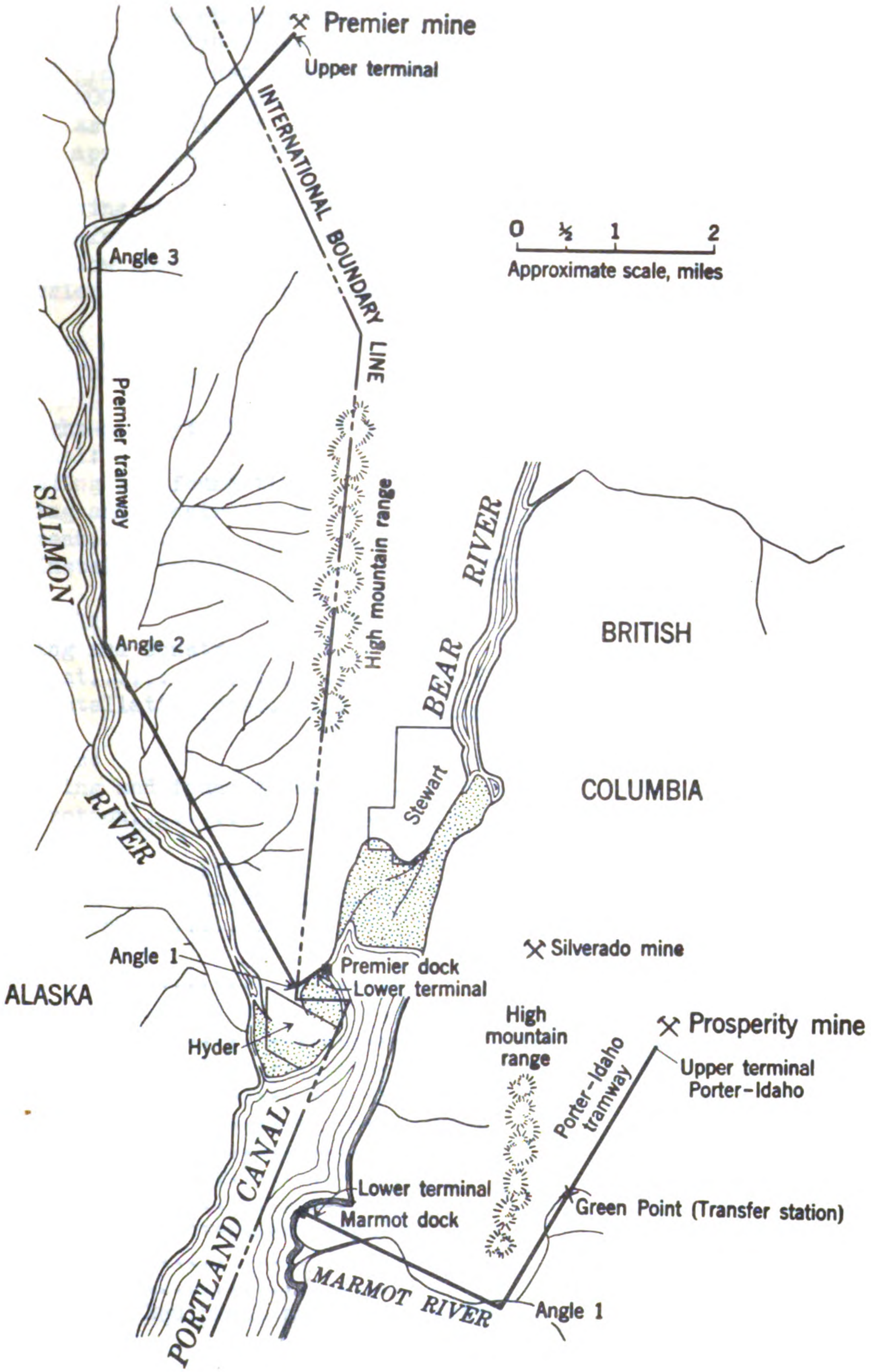

Figure 9.– Map of the Premier and Porter-Idaho tramways.

The track cables were changed from 7/8 inch to 1 inch on the empty side and from 1 inch to 1-1/4 inches on the loaded side. The traction cable was changed from 5/8-inch cast steel to 3/4-inch plow steel and the speed was increased to 600 feet per minute. The number of buckets was increased from 120 to 140. As a result of these changes, the carrying capacity was increased from 12.5 to approximately 17.5 tons per hour.

The driving and control machinery, situated at the loading tunnel, consists of an 8-foot grip sheave and two 50-horsepower motors, one geared for starting and low speeds and the other geared direct by belt for normal running speed. Carriers are of the two-wheeled type and are equipped with Riblet grips.

Complete construction costs, including material, equipment, and installation, are as follows:

| | | | |
|---|---|---|---|
| Clearing right-of-way: Labor and supplies | | | $23,367.95 |
| Upper terminal: | | | |
| Excavating and foundations | | $ 2,140.17 | |
| Building and construction | | 14,839.54 | |
| Equipment | $2,011.16 | | |
| Installation cost | 775.82 | 2,786.98 | 19,766.69 |
| Lower terminal: | | | |
| Building and construction | | 16,803.42 | |
| Equipment | $4,712.27 | | |
| Installation cost | 261.07 | 4,973.34 | 21,776.76 |
| Angle stations: | | | |
| Excavating and foundations | | 2,702.67 | |
| Construction | | 9,929.17 | 12,631.84 |
| Anchorage and tension station: | | | |
| Excavating and foundations | | 5,433.12 | |
| Construction | | 12,679.75 | |
| Tram equipment | | 112,056.89 | 130,169.76 |
| General: | | | |
| Superintendence | | 6,183.84 | |
| Traveling expense | | 2,591.85 | |
| Surveying | | 6,309.06 | |
| Mess house | | 10,699.79 | |
| Accounting | | 2,806.50 | |
| Lumber | | 21,298.92 | |
| Miscellaneous | | 2,794.40 | |
| Right-of-way (Government fees) | | 2,531.90 | |
| Right-of-way | | 3,110.57 | 58,326.83 |
| Building trails | | | 7,353.58 |
| Stringing cable: Equipment and installation | | | 16,188.94 |
| Towers: | | | |
| Excavating and foundations | | 5,681.96 | |
| Framing and erecting | | 20,256.38 | 25,938.34 |

| | | |
|---|---|---|
| Telephone line: | | |
| Equipment | 891.59 | |
| Installation costs | 106.08 | 997.67 |
| Mess and bunk houses erected on line | | 5,457.64 |
| Warehouse | | 222.75 |
| Steamship freight | | 8,372.20 |
| Team hauling | | 24,172.14 |
| Total cost of tramway construction | | 354,743.09 |
| Enlargement of tram bin, March 1923 | | 1,139.41 |
| Installation new tram drive, September 1924 | | 4,307.03 |
| Total capital expenditure | | 360,189.53 |
| Cost per mile (11.5 miles) | | 31,320 |

During the period from 1925 until about 1930 the tramway was operated at full capacity on a three-shift basis, 7 days a week. An average of about 400 tons daily was handled during this entire period. The crew required to operate was as follows:

| | Total |
|---|---|
| Loading terminal, 2 men per shift | 6 |
| Angle stations, 3 men per shift | 9 |
| Lower terminal, 2 men per shift | 6 |
| Foreman, upper terminal, 1 day shift only | 1 |
| Blacksmith, 1 day shift only | 1 |
| Blacksmith helper, 1 day shift only | 1 |
| Linemen, 3 day shift only | 3 |
| Bull gang, 3 day shift only | 3 |
| General superintendent, 1 day shift only | 1 |
| Total | 31 |

Although the carriers were ungripped and gripped automatically at the angle stations, it was considered prudent to have a man stationed at each to insure against accidents. The linemen did all of the routine maintenance work on the towers and tension and anchor stations. Heavy repair work was done by the bull gang under the direct supervision of the general superintendent.

All mine supplies, including pipe, rails, lumber, coal, fuel oil, and food stuffs were transported over the tramway. The major portion was transported by carriers with regular buckets, but special carriers were used for timber, pipe, rails, and fuel oil. Two carriers were used for pipe, rails, and lumber. Loads up to 30 feet in length could be handled in this manner. Fuel oil was transported in special carriers of 42 gallons capacity. When the mine was operated at capacity, an average of 2,150 gallons of fuel oil was hauled daily. From 1924 to 1928, inclusive, 5,000 to 7,000 tons of upfreight was hauled annually.

The first track cables lasted about 4 years (about 520,000 tons) and the traction cables about 3 years (about 375,000 tons). The larger cables that were substituted later lasted longer. Cable wear was greatest where the tramway crossed summits. Replacements were made when necessary and charged to operating expenses. From 1926 to 1928, inclusive, the cable-replacement costs, not including labor, averaged 0.45 cent per ton-mile for the track cable and 0.44 cent per ton-mile for the traction cable. Total operating costs from 1924 to 1928, inclusive, are as follows:

| Account | Costs per ton | | | | |
|---|---|---|---|---|---|
| | 1924 | 1925 | 1926 | 1927 | 1928 |
| Operating: | | | | | |
| Labor | $0.482 | $0.405 | $0.372 | $0.407 | $0.337 |
| Supplies | .015 | .005 | .004 | .002 | .002 |
| Total operating | .497 | .410 | .376 | .409 | .339 |
| Maintenance of terminals and line structures: | | | | | |
| Labor | .028 | .010 | .005 | .019 | .018 |
| Supplies | .005 | — | .003 | .004 | .004 |
| Total | .033 | .010 | .008 | .023 | .022 |
| Maintenance of equipment (including all cable replacements, rolling stock, and telephone line): | | | | | |
| Labor | .208 | .177 | .086 | .153 | .095 |
| Supplies | .192 | .443 | .125 | .199 | .185 |
| Total | .400 | .620 | .211 | .352 | .280 |
| General and overhead: | | | | | |
| Superintendence | .027 | .026 | .023 | .026 | .024 |
| Power | .027 | .026 | .017 | .021 | .020 |
| Miscellaneous lubrication, lights, etc. | .064 | .047 | .044 | .056 | .041 |
| Total | .118 | .099 | .084 | .103 | .085 |
| Grand totals per ton | 1.048 | 1.139 | .679 | .887 | .726 |
| Per ton-mile | .091 | .099 | .059 | .077 | .063 |

## Porter-Idaho[15]

The Porter-Idaho tramway of the Premier Silbak Mine, Ltd., is just south of the Premier tramway and on the opposite side of the Portland Canal. (Fig. 9.) It extends from the Marmot lock on the Portland Canal to the Porter Idaho mine. The total length is five miles. It follows the general course of the Marmot River and the North Fork of the Marmot River for about 3-1/2 miles and then runs directly up a steep mountainside to the Porter Idaho mine.

The tramway profile is very easy from the Marmot dock to the forks of the Marmot River and the North Fork. Beginning a few thousand feet beyond the forks, however, the terrain is very rough all the way to the mine. At one place a 4,200-foot span was necessary to avoid a large area of perpetual snow slides in the winter and rock slides in the summer. Between this point and the mine, all structures (five in all) are rail sections, tension stations, or anchor stations.

All structures, including terminals, are of steel set on concrete foundation piers. Line structures consist of 37 towers, 5 tension stations, 4 rail sections, and an angle station. The angle station is at the fork of the Marmot

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[15] Pitt, Dale L., Work cited in footnote 4 (p. 3).

River and the North Fork. Carriers are detached and attached when entering and leaving this station. An intermediate control station is situated approximately two-thirds of the way from the lower terminal to the mine and at an elevation of about 2,000 feet above the lower terminal and 3,000 feet below the loading terminal. The upper terminal is 105 feet long by 30 feet wide; the lower one is 120 feet long by 30 feet wide and has 1,000 tons bin capacity.

The diameter of the track cables ranges from 1 inch to 1-3/8 inches. The larger sizes are used on the longest spans. All cable sections are anchored at both ends. The traction cable is 7/8 inch in diameter, of plow steel, and is operated at a speed of 550 feet per minute. Driving and control machinery consist of a grip sheave at the loading terminal geared to a 60-horsepower motor and one at the intermediate control station geared to a 40-horsepower motor. Carriers are of 850 pounds capacity and spaced at 800-foot intervals. The rated capacity of the tramway, according to this, is 17 tons per hour. Carriers consist of two 2-wheeled carriages with a bucket suspended between. Two Riblet grips are provided for each carrier to insure safety on steep slopes of 30° or more.

The tramway was operated for only a short time, and therefore operating costs are not available. Construction costs were as follows:

| | | |
|---|---|---|
| Cleaning right-of-way | | $ 9,124.04 |
| Lower terminal | | 19,581.22 |
| Upper terminal | | 13,603.87 |
| Angle station | | 13,097.25 |
| Intermediate control station | | 11,142.44 |
| All line structures | | 33,328.82 |
| Telephone line | | 2,739.99 |
| Cables | $36,366.55 | |
| Installation | 7,377.17 | 43,743.72 |
| Wiring and lighting | | 2,761.13 |
| Tramway equipment | | 51,666.56 |
| Painting all structures | | 1,455.07 |
| Superintendence and engineering | | 17,320.12 |
| Construction equipment | | 6,920.46 |
| Auxiliary tramways: | | |
| Installation | 7,027.53 | |
| Operation | 13,329.33 | 20,356.86 |
| Handling and transporting supplies | | 62,039.87 |
| Temporary living quarters | | 3,355.85 |
| Total cost | | 312,237.27 |
| Cost per mile | | 62,447.45 |

## Silver King Coalition

The Finlayson tramway of the Silver King Coalition Mines Co. is near Park City, Utah. It is used for transporting crude ore and concentrates from the mine and mill to a railroad loading station near Park City and also for hauling coal and other supplies to the mine and mill. For some years timber and hay were hauled to the mine, but this practice has been discontinued. The total length is 7,047 feet. The country through which it passes is mountainous and quite rugged. The loading terminal is at an altitude of 8,150 feet, the highest point is 8,250 feet, and the discharge terminal is 7,500 feet above sea level.

Line structures consist of 38 pyramid towers and 1 tension station, all of steel construction with stone masonry and concrete foundations. The terminals are of timber construction, with bin capacities of 700 tons each.

Track cables are of flattened-strand construction (fig. 6) and of plow steel. The one on the loaded side is 1-1/4 inches and that on the empty side 1 inch in diameter. Tension is maintained by weight boxes suspended at the tension station. The traction cable is 7/8 inch in diameter, 6 by 19 lang-lay construction, and of plow steel; it runs at a speed of 245 feet per minute. Carriers of the 2-wheeled type and 6-cubic-feet capacity are spaced at 184-foot intervals. They are provided with a mechanism for attaching by means of lugs or buttons that are riveted to the track cable. When loaded, they hold 1,000 pounds of lead concentrate or 700 pounds of zinc concentrate. The carrying capacity of the tramway according to this, is 40 tons of lead concentrates or 28 tons of zinc concentrates per hour.

This tramway was built in 1901. The cost of building was approximately as follows: Cost of equipment, $25,000; cost of structural material $15,890; cost of labor for erection, $29,020; total cost $64,920, or $48,750 per mile.

The tramway has been operating almost constantly since it was built. From 1901 to 1937 a total of 1,197,830 tons of ore and concentrates, or an average of 35,230 tons per year, was carried. A total of 90,000 tons of coal, or an average of 2,500 tons per year, was carried on the return or empty side. There is no record of the hay and timber carried.

The 1-inch track cable on the empty side is still in use after nearly 38 years of service. The 1-1/4-inch cable on the loaded side was replaced after 24 years of service. Traction cables last about 3 years. Cable replacement costs, based on list price less a discount of 5-10-5-5 percent for track cables and 20-10-5-5 percent for traction cables, are as follows:

| | Diameter, inches | Duty, tons | Cost per ton mile, cents |
|---|---|---|---|
| Track cable, loaded side......... | 1-1/4 | 800,000 | 0.44 |
| Track cable, empty side.......... | 1 | 1,200,000 | .19 |
| Traction cable.................... | 7/8 | 125,000 | 1.70 |
| Total........................ | | | 2.33 |

## Highland Boy

The Highland Boy tramway of the National Tunnel & Mines Co. is at Bingham Canyon, Utah. It is an unusual installation in that the capacity (100 tons per hour) is larger than that of most tramways used in metal mining. The country through which it passes is rugged and mountainous, but the profile is not extremely difficult. It passes over two summits, one about 6,650 and the other about 8,250 feet above sea level. The loading terminal is at an elevation of 6,750 feet and the discharge terminal 6,500 feet above sea level. The longest span is about 1,100 feet. Several thousand feet of the line ascends slopes of 27°.

The tramway is built in three sections with two intermediate control stations. The first section, from the loading terminal to the high summit, is 4,625 feet long; the second, from the high summit to the second control station, is 3,825 feet long; and the third, from the second control station to the discharge terminal at the smelter, is 12,525 feet long. The total length is 20,975 feet, or approximately 4 miles. On the first section the loads are pulled against an adverse grade that averages about 32-1/2 percent; on the other two sections, the loads travel downhill. The vertical distance from the loading terminal to the first control station is 1,500 feet; from the first to the second control station, 1,500 feet; and from the second control station to the discharge terminal, 1,250 feet.

All structures are built of timber. The loading terminal has seven bins of 150 tons capacity each, and the discharge terminal five bins of 100 tons capacity each. Line structures comprise 78 supporting towers, 1 double-tension station, 1 double-anchor station, 4 combination anchor and tension stations, and 1 rail structure.

Track cables on both loaded and empty side are 1-1/2 inches in diameter and of locked-coil construction. Tension is maintained at 30 tons by means of weight boxes suspended at the tension stations. The traction cable is 1-1/ inches in diameter and 6 by 19 lang-lay construction. It is operated at a spe of 600 feet per minute. The carriers, of 1,200 pounds capacity, are of the tw wheel type and weigh 750 pounds unloaded. They are spaced at intervals of 218 feet; the time interval is 21.6 seconds.

The tramway was built in 1909. In recent years it has been operating only 3 days per week at about 50 percent capacity. In 1928 and 1929, however, it was operated one 7-hour shift per day at a capacity of approximately 95 ton per hour. When operating at full capacity, the operating crew consists of 5 men at the loading terminal, 2 at each control station, 3 at the discharge terminal, 1 foreman, and 1 lineman, a total of 14 men.

The cost of installing the system, not including bins, was $190,000, or $47,500 per mile. When it was operated at full capacity, the operating costs, including all repair, maintenance, and replacement charges, was 28¢ per ton or 7¢ per ton-mile.

## Shenandoah Dives

The tramway of the Shenandoah Dives Mining Co. is in San Juan County, Colorado, about 3 miles northeast of Silverton. It extends from the company mine in Arastra Basin to the mill in the Animas Valley, a distance of 10,000 feet. The difference in elevation of the terminals is 1,500 feet. The profile of the line is moderately steep but otherwise not difficult.

The terminal structures are of timber with concrete foundations. Line structures comprise 2 tension stations, 1 rail section, and 11 square or box-type towers, all of steel construction. The towers are 16 by 16 feet in plan, four of two-bent and seven of three-bent construction. The rail section is 32 feet long. The tension stations, one 20 and one 32 feet long, consist of three bents each. All structures are set on concrete foundation piers.

One and one-quarter-inch plow-steel cables of the half-lock type (fig. 6) are used on both the loaded and the empty side. Cable sections are anchored at both ends. From 30,000 to 35,000 pounds tension is applied at the tension stations by means of heavy blocks. The traction cable is 7/8-inch, lang lay, 6 by 19 construction and of plow-steel grade. Rolling stock consists of 45 carriers of 14-1/2-cubic-foot or 1,450-pound capacity, 7 of 20-cubic-foot or 2,000-pound capacity, and several timber carriers. All ore carriers are of the revolving type and have four-wheel carriages and Carstarphen grips. Only one timber carrier is required for a load of timber or lumber. The traction cable is run at a speed of 500 feet per minute with the carriers spaced at 400 feet. The rated capacity is about 55 tons per hour.

The driving and control machinery situated at the loading terminal, consists of two 6-foot grip sheaves, one geared to a 50-horsepower variable-speed motor and the other to 50-horsepower induction motor. The grip sheaves installed when the tramway was built were not satisfactory and new ones were substituted later. The grips or jaws of the first sheaves were socketed in a continuous groove and depended on gravity to open them for receiving the cable. With the new sheaves, each grip is socketed in a separate pocket with rubber mounting that forces it open when the cable is released. Sheaves of this design are not available as standard tramway equipment. They were designed especially for this tramway by the late D. J. Nevil, of Denver, and were built by the Stearns-Rogers Co. of Denver.

The tramway was designed by F. C. Carstarphen, of Denver, and material and equipment were purchased from various other sources. Construction was begun in the summer of 1929 and completed in the following December. The tramway was put into operation immediately after construction was completed and has been running continuously since.

A stub tram from the upper terminal is used for transferring lumber, timber, powder, and other supplies from the terminal of the main tramway to the level of the timber yard, shops, and hotel, 100 feet above the terminal. Carriers loaded with freight are switched from the main tramway to the stub tramway. From the upper end of the stub tram they are run on overhead rails to the timber yard, warehouse, hotel, or wherever the freight is to be delivered.

An advantage of the square type of tower used in this tram is that it increases the number of points of support, thereby diminishing the magnitude of the deflection angles. Each tower had two or three saddles for each cable instead of one, as in the case of most standard types of supporting towers. When the main tramway was first built, it was equipped with standard rocking saddles; those on the loaded sides were replaced by the continuous grooved rails (fig. 7) that already have been described in connection with the general discussion on saddles. Inverted 90-pound railroad rails are used on the structures having three points of support at 8-foot centers and 12-inch I-beams on those having only two points of support at 16-foot centers.

The seven 20-cubic-foot buckets are of all-welded construction and were made up at the mine shop from 12- or 15-gage silicon-manganese steel. These buckets decrease the tare weight of the carriers from 780 to 600 pounds and increase the carrying capacity from 1,430 to 2,000 pounds.

Eighteen hundred feet of track cable on the loaded side was replaced after 3 years use. This showed a small decrease in diameter but was otherwise in good condition. Other replacements consisted of short sections at five points; at the places where the wear is most severe, a life of 2 years can be anticipated. These replacements have been charged to current operating expenses. Up to December 1937, two track cables had been replaced. The first one had transported 563,000 and the second one 834,000 tons of ore. Damage caused by accidents made it necessary to replace both cables at an earlier date than otherwise would have been necessary. The replacement costs were $0.0035 per ton-mile for the first cable and $0.0024 per ton-mile for the second.

Five men normally are required to operate the tramway - two at the loading terminal, two at the discharge terminal, and a foreman. When powder, timber, and other supplies are sent to the mine, extra men must be put on as freight handlers. In the costs shown here, it should be noted that credit is given the tramway for freight handling on the main line but none for operating the stub tram, which is used exclusively for freight. After making an adjustment for this, the costs per ton-mile for handling ore only are approximately 5.13 cents, instead of 6.13 cents as shown. The costs broken down for October 1937 are as follows:

17,797 tons of ore trammed and milled: 6.4- to 8-hour shifts at 294.6 tons per shift; length, 2 miles (approximate)

| Account | Amount | Totals | Per ton | Per ton mil |
|---|---|---|---|---|
| Supervision................ |  | $271.35 | $0.0152 | $0.0076 |
| Labor: |  |  |  |  |
| Operators, main tramway. | $1,096.40 |  | .0616 | .0308 |
| Operators, stub tramway. | 356.56 |  | .0199 | .0099 |
| Operators, freight handlers | 461.96 |  | .0259 | .0130 |
| Total labor......... |  | 1,911.92 | .1074 | .0537 |

17,797 tons of ore trammed and milled; 6.4- to 8-hour shifts at 294.6 tons per shift; length, 2 miles (approximate) cont'd.

| Account | Amount | Totals | Per ton | Per ton mile |
|---|---|---|---|---|
| ire insurance........ | | 60.56 | .0034 | .0017 |
| ubrication.......... | | 8.10 | .0005 | .0002 |
| iscellaneous items.. | | 14.42 | .0008 | .0004 |
| axes............... | | 28.96 | .0016 | .0008 |
| ools............... | | 39.29 | .0022 | .0011 |
| aintenance and repairs: | | | | |
| Buildings......... | 2.80 | | .0002 | .0001 |
| Cables............ | 137.98 | | .0078 | .0039 |
| Power and electric plant........... | 160.69 | | .0090 | .0045 |
| Rolling stock...... | 16.95 | | .0009 | .0005 |
| Towers............ | 19.04 | | .0011 | .0005 |
| otal maintenance and repairs............. | | 337.46 | .0190 | .0095 |
| ross operation...... | | 2,672.06 | .1501 | .0750 |
| ess credit for up freight............. | | 490.72 | .0275 | .0137 |
| et tramway operating | | $2,181.34 | .1226 | .0613 |

The tramway is used for passenger service as well as for freight and ore. any of the men who work at the mine live in Silverton and make the round trip o the mine each day on the tram. Up to December 1, 1937, 2,000,000 passenger ound trips and 8,000,000 passenger miles had been made over the line. About 2,500 tons of freight is taken to the mine each year. To date, (March 1939) pproximately 1,800,000 tons of ore have been handled. When operated to capacity ithout interruption, 1,100 tons of ore can be handled in 20 hours. The cost of he main tram was $126,000, or $63,000 per mile. The stub tram cost $7,500 extra.

## Peru

The tramway of the Peru Mining Co. at Hanover, N. Mex., is used for carrying rude ore from the mine to a railroad loading station, a distance of 2,225 feet. The country is moderately rough, with a fairly uniform slope from the loading terminal to the discharge terminal, 300 feet vertically below.

All structures are built of timber. The loading terminal has a bin apacity of 450 tons and the discharge terminal 275 tons. Line structures omprise five supporting towers of the through type. At the end of the loading terminal is a short break-over structure.

The track cable on the loaded side is of smooth-coil construction and 1 inch in diameter; on the empty side, smooth-coil construction and 3/4-inch diameter is employed. They are anchored at the loading terminal and weighted at the discharge terminal. Traction cable is of 6 by 19 lang-lay construction, 1/2 inch in diameter and operated at a speed of 400 feet per minute. Carriers are of the two-wheeled type, of 800 pounds capacity, and spaced at 300-foot intervals. The carrying capacity of the tramway on this basis is 32 tons per hour. It actually delivers around 420 tons in two 8-hour shifts, or about 26 tons per hour.

Driving and control machinery consists of a 15-horsepower motor geared to a 60-inch-diameter smooth sheave located at the loading terminal.

The tramway was built of used equipment, and construction costs are not available. Three men are required to operate, two at the loading terminal and one at the discharge terminal. Labor for operating is contracted for at 5 cents per ton. Operating costs for 1937 were as follows:

Number of tons transported - 118,600

| | | | |
|---|---|---|---|
| Labor | $6,404.00 | 5.4 | cents per ton |
| Maintenance | 1,186.00 | 1.0 | do. |
| Replacements | 1,768.00 | 1.5 | do. |
| Total | 9,358.00 | 7.9 | do. |

## Bagdad

The tramway of the Bagdad Copper Co. at Bagdad, Ariz., is of the double-reversible or jig-back type. It is one of a comparatively few systems of its type and capacity to be found in the metal-mining industry in the western United States. Most reversible tramways in the industry are of very limited length and capacity and will be found principally at small mining plants that do not require a transportation system of great carrying capacity.

The Bagdad tramway can carry about 300 tons in 8 hours, or approximately 38 tons per hour. It is used for transporting copper ore from the mine to the mill, a distance of 780 feet. The country is fairly flat, but there is enough slope for the loads to run by gravity.

Track cables are of locked-coil construction and 1-1/2 inches in diameter Traction cable is of 6 by 19 regular-lay construction and 1/2 inch in diameter The carriers are of 1-ton capacity and dump automatically. The driving mechanism consists of a small mine hoist with a single wood-lagged drum geare to a 15-horsepower reversible motor. Two turns of the traction cable around t drum provides enough friction for propelling and controlling the loads.

One man does the loading and operates the hoist. Dumping at the discharg terminal is automatic. Detailed tramming costs are difficult to determine accurately; the tramway operator on night shift operates a crusher also, and the day-shift operator runs the tram only; the night-shift operator runs the tram about 2 hours and puts in the rest of the shift at the crusher. On this basis, the tramming costs are about 3 cents per ton. During December 1938 and January, February, and March, 1939, 29,198 tons of ore was handled.

## San Francisco Mines of Mexico, Ltd.

The tramway system of the San Francisco Mines of Mexico, Ltd., at an Francisco del Oro, Chihuahua, Mexico, has already been mentioned in the hapter on underground construction. The present system is the third that has een in use during the period of active operation of the property, which began rior to 1906. The first tramway, which had a capacity of 300 tons in 24 hours, as replaced in 1911 by one having a capacity of 500 tons in 24 hours. This was eplaced in 1934 by the present system, which has a rated capacity of 110 metric ons, or approximately 121 short tons per hour. It is actually operated at a apacity of 2,100 metric tons a day.

The complete system comprises two separate tramways or divisions, each of hich is built in two sections. It is of more than usual interest because of he underground feature of one section of the San Francisco division and also ecause of the great flexibility of the system as a whole. Ore from three ines is handled jointly by the two divisions. Each division can be operated ndependently of the other, and one section of each division can be operated ndependently of the rest of the system.

The San Francisco division has a total length of 7,890 feet. The lower ection extends from the Hacienda mill to an angle station near the portal of he La Tinta adit, a distance of 4,820 feet; the other extends from the angle tation into the adit for 3,070 feet to an underground loading station near he San Francisco shaft. The first section handles the ore from the Clarines ramway, which has its terminal at the La Tinta angle station, as well as that rom the underground loading station of the San Francisco mine. Both sections re controlled by one motor situated at the Hacienda Mill terminal and geared o a grip sheave. Power is transmitted from one section to the other through wo grip sheaves at the La Tinta angle station and connected by a clutch mechanism o that the first section can be operated independently of the other.

The ground profile from the Hacienda mill to the La Tinta angle station is elatively flat and even. Line structures on this section of the tramway comrise 3 rail sections, each 22 feet in length, and 7 pyramid towers. The disharge terminal is 210 feet in length, with 126 feet of dumping space and 3,000 etric tons bin capacity. The La Tinta angle station is 182 feet in length. All tructures are of steel on concrete foundation piers. Construction practices sed on the underground section of the tramway are described in the chapter on nderground construction. Old worked-out stopes were utilized for underground oading bins. Ore is loaded from these bins directly into the tramway carriers hrough six loading chutes. The total capacity of the bins is 7,000 metric ons; the total length of the loading station is approximately 286 feet.

Seven-eighths-inch locked-coil cable is used on the empty side and 1-1/2-nch on the loaded side. Tension on the loaded side is maintained at 30 tons and n the empty side at 12 tons by concrete blocks suspended at the La Tinta angle tation and the Hacienda terminal. The traction cable is of 6 by 7 lang-lay onstruction 5/8 inches in diameter and of plow-steel grade. It is operated at speed of 500 feet per minute. The carriers, of the two-wheeled type, have a apacity of 1 metric ton of sulfide ore or 800 kilograms (1,730 pounds) of oxide re. The average carrying capacity of the tramway when handling oxide and sulfide res is around 110 metric tons (123 short tons) per hour.

About 190 tons of steel was used in the construction of this tramway. Track and traction cables, tension-station and anchor-station equipment, terminal machinery, line couplings, and saddles were furnished by contract by the American Steel & Wire Co. at a cost of $52,000. The cost of structural material, including steel, concrete, and timber, was $30,000. Installation costs, including labor, supervision, engineering, etc., were $34,000, making a total of $116,000, or approximately $77,333 per mile.

The Clarines tramway has a total length of 16,460 feet (3.12 miles). One section extends from the discharge terminal at the La Tinta angle station to the La Mesa loading station, a distance of 8,021 feet, the other from the La Mesa loading station to the loading terminal at the Clarines Mine, a distance of 8,304 feet. Ore from the El Toro mine is loaded at the La Mesa loading station. Both sections are driven or controlled by one 40-horsepower motor at the La Mesa loading station geared to a grip sheave. This grip sheave is connected by a clutch mechanism to another, which operates the second section. The arrangement is similar to that at the La Tinta angle station of the San Francisco division, except that the motor and both grip sheaves are at one station, whereas at the San Francisco tramway two grip sheaves are at one station while the motor and one grip sheave are at another. Carriers from the Clarines mine pass directly through the La Mesa loading station on their way to the discharge terminal at the La Tinta angle station of the San Francisco tramway. When handling ore from the La Mesa bins, the second or Clarines section can be unclutched and the first section operated independently.

The ground profile of this division is more difficult than that of the San Francisco. The terminals are at about the same elevation, 6,700 feet above sea level; the highest intermediate point is 7,700 feet above sea level.

Terminals and all intermediate structures are of steel with concrete foundations. The Clarines loading terminal has a bin capacity of 1,200 tons, the La Mesa loading station 300 tons, and the La Tinta discharge terminal 1,200 tons. The track cable on the loaded side is 1-1/4-inch locked-coil construction, on the empty side 7/8-inch locked-coil construction. The traction cable is of 6 by 7 lang-lay construction, 3/4 inch in diameter, and of plow steel. It is operated at a speed of 500 feet per minute. The carriers, of the two-wheeled type, have a capacity of 500 kilograms (1,170 pounds) of sulfide ore and a little less of oxide ore. The carrying capacity of the tramway is 50 metric tons of sulfide ore per hour, or 40 tons of oxide ore per hour.

Both the San Francisco and the Clarines tramways are semiautomatic in operation. The overhead rails at the terminals are set at enough grade so that the carriers run by gravity from the point at which they are detached from the traction cables to where they are loaded from hand-operated chutes. From the loading chutes they run by gravity to automatic attachers, where they are held by an operator until the proper time for dispatching. Dumping at the discharge terminals is done automatically by a tripping device that can be moved to any point where dumping is desired. In passing through angle and intermediate control stations, the carriers are detached from one section and attached to the other entirely by mechanical means.

Traction cables are good for about 1,000,000 metric tons. After a cable as been used for about 600,000 tons on the heavy-duty or surface section of he San Francisco tramway, it is changed to the underground section, where it ives an additional service of 400,000 metric tons. Track cables on the an Francisco tramway are still good after 5 years of use, during which time pproximately 600,000 metric tons a year, or a total of 3,000,000 metric tons f ore, was transported.

Operating crews consist of 7 men per shift on the Clarines tramway and 9 n the San Francisco. Besides the regular operating crews, there is a crew of ine men who do repair, maintenance, and cable-replacement work. The total verage crew and the wage rates (Mexican currency) for the year ended eptember 1938 is as follows:

verage tramway crew during fiscal year ended September 30, 1938

| larines tramway | Men | Pesos | |
|---|---|---|---|
| larines loading station: | | | |
| 1 dispatcher at 5 pesos per shift | 3 | 15.00 | |
| 1 loader at 4.5 pesos per shift | 3 | 13.50 | |
| 1 operator at 4.5 pesos per shift | 3 | 13.50 | 42.00 |
| ntermediate loading station: | | | |
| 1 motor operator at 5 pesos per shift | 3 | 15.00 | |
| 1 helper at 4.5 pesos per shift | 3 | 13.50 | 28.50 |
| ischarge terminal: | | | |
| 1 dispatcher at 5 pesos per shift | 3 | 15.00 | |
| 1 operator at 4.5 pesos per shift | 3 | 13.50 | 28.50 |
| epair crew: | | | |
| 1 repair foreman | 1 | 6.50 | |
| 1 repair helper | 1 | 4.50 | |
| 1 Oiler | 1 | 4.50 | 15.50 |
| Total | 24 | | 114.50 |
| an Francisco tramway | | | |
| nderground loading station: | | | |
| 1 dispatcher at 5 pesos per shift | 3 | 15.00 | |
| 4 operators at 4.5 pesos each | 12 | 54.00 | 69.00 |
| ngle station: | | | |
| 1 operator at 4.5 pesos per shift | 3 | 13.50 | 13.50 |
| ischarge terminal: | | | |
| 1 motor operator at 5 pesos per shift | 3 | 15.00 | |
| 1 dispatcher at 5 pesos per shift | 3 | 15.00 | |
| 1 operator at 4.5 pesos per shift | 3 | 13.50 | 43.50 |

| San Francisco tramway (Cont'd) | Men | Pesos | |
|---|---|---|---|
| Repair crew: | | | |
| 1 repair foreman | 1 | 9.50 | |
| 1 cable repairman | 1 | 9.75 | |
| 1 cabo menor | 1 | 6.50 | |
| 1 oiler | 1 | 4.50 | |
| 1 repairman | 1 | 5.00 | |
| 1 repairman | 1 | 4.50 | 39.75 |
| Total | 33 | | 165.75 |
| General: | | | |
| 1 truck driver | 1 | 6.00 | 6.00 |
| Total per day | 58 | | 286.25 |

Operating costs of the Clarines tramway are slightly greater than those for the San Francisco. The costs shown in the following table are for a total of 570,710 metric tons of ore hauled over the surface section of the San Francisco tramway. Of this, 43,190 metric tons was from the El Toro mine and 128,580 metric tons from the Clarines mine. All costs are in United States currency.

Aerial tramway cost per metric ton, 12 months ended September 30, 1938

| | Clarines | San Francisco | La Mesa | Over-all total |
|---|---|---|---|---|
| Distance in miles.... | 4.00 | 1.5 | 2.43 | 1/ 2.13 |
| Metric tons hauled... | 128,580 | 389,940 | 43,190 | 570,710 |
| Labor and bosses..... | $ 0.1100 | $ 0.0414 | $0.0851 | $ 0.0602 |
| Supplies............. | .0252 | .0094 | .0201 | .0138 |
| Power................ | .0033 | .0011 | .0023 | .0017 |
| Shops and miscellaneous........... | .0140 | .0056 | .0125 | .0078 |
| Total........... | .1525 | .0575 | .1200 | .0835 |
| Per metric ton-mile.. | .03815 | .0384 | .0493 | .0392 |
| Per ton-mile......... | .0340 | .0342 | .0430 | .0350 |

1/ Average.

Replacements, including 10,000 feet of 5/8-inch traction rope, and major repair items requisitioned during the above period amounted to $3,150.00 United States currency or 0.0055 per metric ton, virtually all of which was for the San Francisco tramway.

## Summary

A summary of costs and other data from the foregoing description of individual tramways is shown in table 4.

| Tramway | Location | Capacity, tons per hour | Length, miles | Construction material | Installation Cost | | Operating costs | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Total | Per mile | Per ton | Per ton mile |
| Kennecott............ | Kennecott, Alaska........ | 21 | 2.86 | Timber | $105,519 | $37,000 | [1] $0.371 | $0.135 |
| Premier.............. | Premier, British Columbia | 17.5 | 11.50 | do. | 360,189 | 31,320 | .895 | .078 |
| Porter Idaho......... | Premier, British Columbia | 17 | 5.00 | Steel | 312,237 | 62,447 | -- | -- |
| Silver King Coalition. | Park City, Utah.......... | 40 | 1.33 | do. | 64,920 | 48,750 | -- | -- |
| Highland Boy......... | Bingham Canyon, Utah..... | 100 | 4.00 | Timber | 190,000 | 47,500 | .280 | .070 |
| Shenandoah Dives...... | Silverton, Colo.......... | 55 | 2.00 | Steel | 126,000 | 63,000 | .103 | .051 |
| Peru................. | Hanover, N. Mex.......... | 32 | 0.42 | Timber | -- | -- | .079 | -- |
| Bagdad[2]............. | Bagdad, Ariz............. | 38 | 0.15 | do. | -- | -- | .030 | -- |
| San Francisco......... | San Francisco del Oro,<br>Chihuahua, Mexico...... | 123 | 1.50 | Steel | 116,000 | 77,333 | .051 | .034 |
| Pecos................ | Pecos, N. Mex........... | 50 | 12.00 | do. | -- | -- | .354 | .029 |

[1] Includes amortization costs at 6 percent.

[2] Double-reversible type, all others are double-rope continuous.

## CONCLUSION

Aerial tramways are probably the most highly specialized means of transportation known to the mining industry. They were developed primarily for use in countries of rough topography, where other methods were impractical and in many cases impossible. Their dependability and efficiency for this purpose were proved so effectively in the early days of their development that they eventually came into prominence in the coal-mining, quarrying, and construction industries in direct competition with nearly every other known means of transportation.

Construction costs in mountainous countries, as indicated in table 4, range from $30,000 to $65,000 per mile for systems of moderate capacity. For systems having capacities of 100 tons per hour, or more, the costs are as high as $77,000 per mile. Operating costs for systems of moderate length and capacity, such as are ordinarily used in the metal-mining industry in the United States, Canada, and Alaska, range from 5 to 10 cents per ton mile. Direct operating costs[16/] for the 12-mile tramway of the American Metal Co. at Pecos, N. Mex., range from 2.1 to 3.7 cents per ton-mile. In Mexico, operating costs, including depreciation, run as low as 3.3 cents per ton-mile on systems of moderate length. This is possible because of semiautomatic equipment, large tonnage, and low labor costs. Apparently, lower costs at metal-mining plants in the United States and Canada will be possible only by the use of more automatic or semiautomatic equipment. This is possible at plants where only ore is handled but not where much back freight must be carried as well.

Comparisons of transportation costs by aerial tramways with other methods are difficult and sometimes meaningless. So many factors must be taken into account that it is often impossible to calculate figures that show a true comparison. Haulage costs by truck are greatly affected by the methods of loading and unloading, and with aerial tramways by the amount of back freight that must be handled. At the Premier mine in British Columbia, where a relatively large amount of back freight was handled by the tramway, the cost ranged from 5.8 to 9.9 cents per ton-mile; at the Pecos mine of the American Metal Co. in Pecos, N. Mex., where no back freight was handled, the cost ranged from 2.1 to 3.9 cents per ton mile.

Gardner[17/] shows trucking costs for Arizona, California, Montana, and Nevada. Costs for distances of 1 to 20 miles and for jobs that require no shoveling range from 5 to 30 cents per ton-mile. Aerial-tramway costs for distances of 1 to 12 miles, including systems where back freight is handled, range from 2.1 to 13.5 cents per ton-mile. In places where a direct comparison is possible, tramways show about the same and sometimes a greater advantage over trucks. For instance, at the Peru mine in Hanover, N. Mex., tramway

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[16/] Matson, J. T., and Hoag, C., Mining Practice at the Pecos Mine of the American Metal Co. of New Mexico: Bureau of Mines Inf. Cir. 6368, 1930, 21 pp.

[17/] Gardner, E. D., Costs of Trucking and Packing Ore in Western Gold-Mining Districts: Bureau of Mines Inf. Cir. 6898, 1936, 17 pp.

transportation costs from the mine to the railroad loading station are around 8 cents per ton; the lowest bid made by a trucking contractor was 15 cents per ton.

At its present stage of development, the aerial tramway is a rigid system, suitable only for transportation between fixed points. It is possible that this is one of the reasons why tramways have fallen into disfavor with metal-mine operations in recent years. Modern industry requires in its transportation systems a flexibility that has not yet been developed in aerial tramways. Another reason for the lack of interest in this means of transportation by metal-mine operators is the present tendency toward small operating units where there is not a sufficient ore reserve to justify the capital expenditure necessary for an elaborate and expensive transportation system.

Greater flexibility might greatly enhance the use of aerial tramways in certain metal-mining fields such as small open-pit mining. Here, the reversible tram with a movable loading terminal might be used to advantage, provided large boulders are not too much of a problem. Whether or not a movable loading terminal is practical is open to some doubt, but movable towers used in connection with slack-line systems would indicate that they are. Tramways of moderate capacity that could be dismantled easily and at a low cost and reinstalled at other properties, might find favor with metal-mining companies that operate mines in different places. The success of such development would seem to depend primarily on more standardized construction practices, and also on a more thorough knowledge and understanding among mine operators and mining engineers of the principle and practices involved in construction and operation.